ENVIRONMENT ASSESSMENT TECHNICAL REPORTS

Scanning the Global Environment: A framework and methodology for integrated environmental reporting and assessment

R. J. Swart and J. A. Bakkes (eds.)
L. W. Niessen, J. Rotmans, H. J. M. de Vries and R. Weterings

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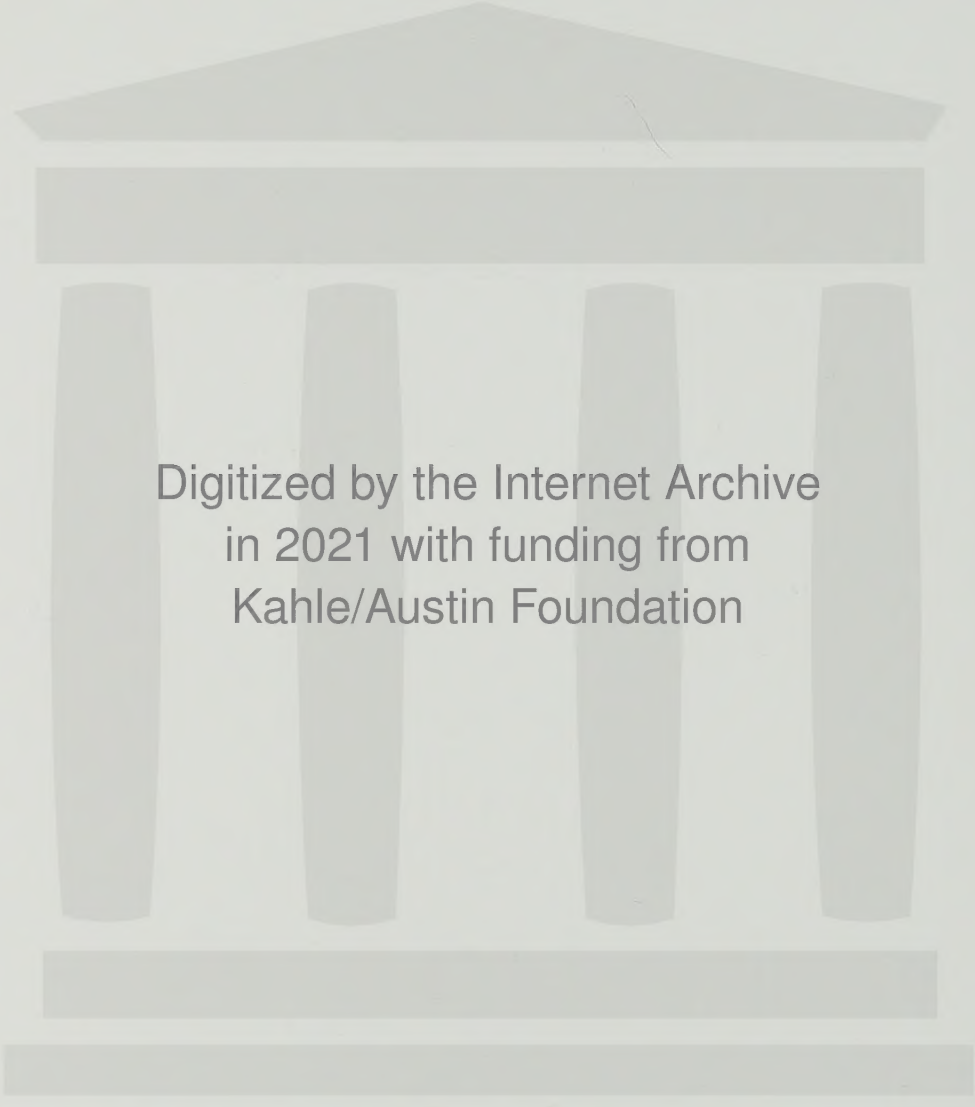
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Scanning the global environment

A framework and methodology for integrated environmental reporting and assessment

R.J. Swart and J. Bakkes (eds.), L. Niessen, J. Rotmans and H.J.M. de Vries
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ABSTRACT

The development and elaboration of strategic environmental policy needs better support. To this end, information should be provided about the past, current and future state of the environment as a function of demographic and socio-economic developments. In this report a framework is sketched for this type of assessments at the regional and global level.

The policy relevance of the global environmental reporting and assessment functions could be improved considerably by introducing three new elements:

1) the application of integrated frameworks and computer models to allow for the analysis of the dynamic linkages between different environmental changes, between environment and development, and for early warning purposes and prognosis;
2) a framework of appropriate indicators related to the pressure on the environment, the state-of-the-environment, the resulting impacts on functions of the environment and the societal response; for these indicators to be policy-relevant appropriate reference values should be selected and developed;
3) networks of experts and expert institutions for assessment and consensus building on key environmental issues.

This report focuses on the first two elements. A framework is proposed, including environmental indicators and models describing the human system, the environmental system and their interactions. This framework is integrative in the sense that integrated models are used to link the system components dynamically. Forecasts for early warning purposes can be supported by model-aided development of consistent sets of scenarios. A hierarchical set of indicators is proposed, as much as possible based on the output of regional and global environmental modelling. These indicators can be developed for different geographical levels, different environmental themes and different societal sectors. Consensus building on reference values is necessary for appreciation of reported indicators. The Pressure-State-Impact-Response framework is used as an organizing principle for indicators in the environmental management cycle.

LIST OF CONTENTS

page

Abstract iii

List of contents v

Preface vi

PART I: INTRODUCTION AND FRAMEWORK

1 Background, objectives and key issues
- 1.1 Background and objectives of this report 1
- 1.2 Objectives of integrated environmental reporting and assessment 1
- 1.3 Key issues in this report 4
- 1.4 A vision on future outputs 5

2 A framework for environmental reporting and assessment
- 2.1 The framework 7
- 2.2 Towards a structured reporting and assessment methodology 8
- 2.3 Interlinked models at various aggregation levels 11
- 2.4 Forecasting and scenario development 13
- 2.5 Models as interfaces between science and policy design 14

3 A set of indicators
- 3.1 Introduction: the relation between indicators and models 17
- 3.2 Criteria for selection and development of indicators 17
- 3.3 Types of reporting 20
- 3.4 Reference values 21
- 3.5 Visualization 23

PART II: THE SUBSYSTEMS

4 Model and data requirements
- 4.1 Feasibility of an integrated modelling approach 27
- 4.2 Data management for integrated assessment and reporting 27

5 An integrated approach to the environmental system
- 5.1 Introduction 29
- 5.2 Environment system models 30
- 5.3 Indicators of the environment system 34
- 5.4 Towards reference values 35

6 The human system
- 6.1 The economic subsystem 39
- 6.2 The population subsystem 42

APPENDICES

I References 47

II The Environment in Europe: an example of integrated assessment modelling at the regional level 51

PREFACE

Dear Reader,

There is a growing awareness among national governments and international organizations that it is impossible to separate socio-economic development issues from environment issues: most forms of development impact the environmental resources upon which they are based, resulting in environmental degradation which, inturn, undermines social and economic development. Addressing the dynamic interactions between environment and development requires more than scientific education and statistical quantification of the status of and trends in natural resources and pollution.

New requirements for environmental information and assessments as stipulated, for example, in Agenda 21 include:

- integrated and timely access to data and information from many different sources and disciplines;
- analysis of environment-development interactions, and policy and management options;
- identification of cause and effect relationships as well as emerging issues of potential international importance;
- assessment of potential impacts and long-term sustainability of alternative development, policy or management scenarios.

To address such needs, we must develop, and use new ways of thinking, compiling, handling and assessing environmental information, new frameworks for organising and integrating relevant information, and new methods and tools to assess the information and communicate results to decision-makers.

The Environment Assessment Technical Report series aims to explore and review new developments and initiatives in integrated environmental assessment methodology, to assess and propose possible new approaches for international environmental assessment and reporting, and to communicate them for worldwide review.

Presenting methodological issues, techniques and proposals in this series does not necessarily mean that UNEP subscribes to them. Rather the series is intended to distill and present promising new developments, stimulate discussion, and thereby promote international consensus on the way forward. We hope this will contribute to the wider use of more efficient approaches and procedures in assessing and reporting on development and progress.

We, therefore, welcome your comments on the contents of this publication and will be pleased to learn from your experiences and listen to your suggestions.

H.Croze
Assistant Executive Director
United Nations Environment Programme

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PART I

INTRODUCTION AND FRAMEWORK

CHAPTER 1

BACKGROUND, OBJECTIVES AND KEY ISSUES

1.1 BACKGROUND AND OBJECTIVES OF THIS REPORT

Agenda 21 was adopted at the United Nations Conference on Environment and Development in Rio de Janeiro as the global action plan aiming to achieve sustainable development. To allow decision makers to plan for sustainable development and appraise progress being made towards the objectives of Agenda 21, information on the past, current and future state of the environment as a function of demographic and socio-economic development is essential. Assessments can play a major role in this process by providing:

1. an integrated view on environment and development: integrating environmental and socio-economic issues, and analyzing the impact of driving forces on the services / functions the environment provides;
2. ex ante evaluation of the environmental effects of alternative socio-economic scenarios and broad policy options;
3. an explicit policy-oriented interpretation of available data and scientific knowledge.

This report is intended to explore ways in which integrated reporting and assessment can be based on a systematic, policy-relevant evaluation of the past, current and future state of the environment. "Reporting" here refers to the preparation and distribution of documents and other information about the environment, while "assessment" refers to the appreciation of this information by scientists for supporting policy development, applying their expertise and using appropriate tools.

Current reporting is characterized by an emphasis on data with insufficient policy-relevance, sometimes complemented by evaluations by selected experts. This report deals with the methodological innovation that is necessary to make reporting more systematic, broad-based and policy-relevant. This report is not in the first place meant for the reader who wants to get an impression of the content of integrated assessments. Other publications are in preparation to do just that. Nevertheless, we have included an example from existing material as an appendix.

1.2 OBJECTIVES OF INTEGRATED ENVIRONMENTAL REPORTING AND ASSESSMENT

The international community through United Nations fora such as the General Assembly (GA), the Governing Council of the United Nations Environmental Programme (UNEP-GC), the United Nations Conference of Environment and Development (UNCED), and more recently the Commission on Sustainable Development(CSD) has expressed repeatedly the need:

> **"to keep under review the state of the global environment, enhance understanding of the critical linkages between environment and human activities, identify priorities for international action, flag emerging issues and strengthen national and regional information-handling capacities for sustainable development"** (UNEP,1994).

At present, there is inadequate knowledge on the state of the environment and its linkages with development and socio-economic issues at the global and the regional level. Information necessary to assess the impacts of demographic and developmental trends on environmental processes is often not available or known. Yet, this information is required to identify emerging issues and priorities for collective action in the context of sustainable development at international, regional and national levels. Given the paucity of relevant information, a global reporting and assessment system needs to be primarily targeted at addressing the following question:

> *Which environmental issues and priorities deserve special attention by the international community?*

In order to answer this question, a global reporting and assessment system would have to enable comparison across regions and environmental issues in the broader context of sustainable development. In accordance with the policy life cycle (figure 1-1), the following objectives could therefore be set.

1. Identifying and articulating environmental issues

- Agenda formation, e.g. through the UNEP's Governing Council, CSD. Contribution to the periodic revision of Agenda 21 and related policy plans.
- Raising awareness, e.g. by providing feedback of environmental information to the broader public.

- Identification of gaps in data and knowledge, for research and monitoring.

2. Supporting policy development

- Identification and analysis of driving forces; highlighting interactions between environment and development issues.
- Identification of policy options, associated costs and effectiveness, and ex ante evaluation of proposed policy options.
- Proposing regional and thematic priorities within the UN system and proposing priorities by donor agencies (bilateral, Global Environment Fund (GEF)).

3. Evaluating policy implementation

- Progress appraisal in the broad context of Agenda 21[1].
- Evaluation of effectiveness of policy responses.

In order to reach the above objectives, we recommend incorporating three new elements in a global reporting and assessment system. First, integrated conceptual and computer simulation models would be introduced to allow for the analysis of the dynamic linkages between the state of the environment and demographic and socio-economic development and for the construction of outlooks, scenarios and forecasts for early warning purposes.

Second, we recommend selecting appropriate indicators for the state-of-the-environment, the pressure on the environment, environmental impacts and the societal response to environmental changes. This hierarchical set of indicators should, as far as possible, be based on the quantitative output of regional and global environmental modelling, existing monitoring systems and adjusted to policy requirements. In addition, appropriate reference values should be developed for these indicators to evaluate progress being made towards sustainable development.

Third, although outside the remit of this report, we would propose broadening and strengthening networks of experts and centres of excellence, in order to facilitate scientific and policy assessment and consensus building on key environmental issues. We believe that these networks would be of major importance in forming an international agenda that reflects the different viewpoints about which environmental issues should be given priority within the international and regional communities.

[1] This appraisal would focus on the broad strategic lines and thus be different from year-to-year policy performance monitoring.

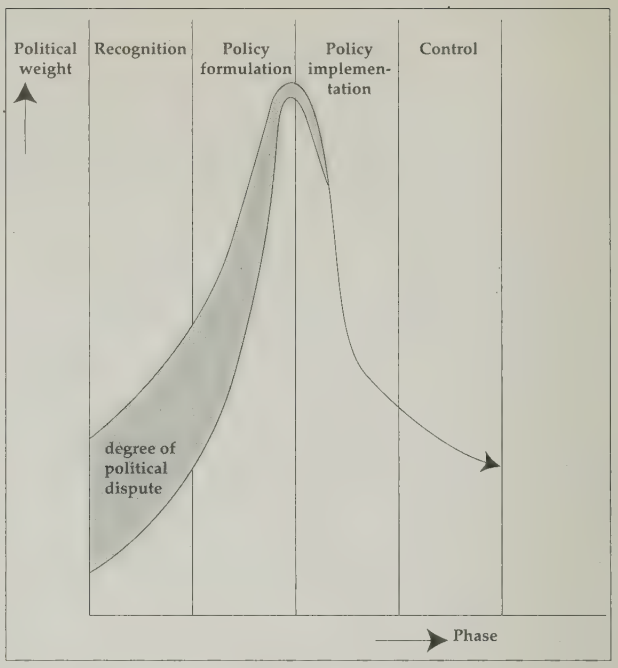


Figure 1-1: Policy Life cycle (Winsemius, 1987).

1.3 KEY ISSUES IN THIS REPORT

This report focuses on the first two issues: integrated models and the related set of indicators. It consists of two parts. In *Part I* we propose a framework, describing environmental indicators and simulation models for assessing interactions between society and the environment and the past, current and potential future state of the environment. In *Part II* we elaborate in more detail on the models and indicators for reporting about the environment and society (economy and population/health), respectively.

The main conclusions in this report are that:

1. *The application of integrated modelling, using a purpose-built set of indicators, could significantly increase the policy relevance of global and regional environmental reporting and assessment.*

2. *The feasibility of such an approach for different environmental themes has already been proven at the national level, and no fundamental obstruction to applying the methodology at the regional and global level is evident.*

With respect to causality, we note that current reporting systems generally focus on each of the elements of the causality chain separately, thus masking important information on system delays and interconnections. For global and regional reporting, the development of a consistent set of scenarios and a coordinated data management system would help to integrate the different subsystems

in a coherent fashion. It would support international efforts in the areas of early warning, periodic review, and the identification of emerging issues. Decision makers in national governments and in multilateral organisations would thus be supported in setting priorities.

Evidently, the proposed framework is not yet operational. No appropriate indicators for many environmental themes have been agreed yet, nor are practicable simulation models at the regional or world level always available. However, several integrated modelling techniques and associated sets of indicators for the different elements of the environmental management system are being developed. The strength of these techniques would be greatly enhanced if the efforts in different sectoral areas could be integrated into a comprehensive regional and global reporting and assessment.

This process of integration can be reinforced through global networks of research and monitoring institutions. The efforts under way in the industrialized countries of the OECD should be complemented by parallel and joint efforts in the less-industrialized countries in order to fully acknowledge their special situation, their rich knowledge and different priorities.

1.4 A VISION ON FUTURE OUTPUTS

Developing a framework for comprehensive reporting functions must go hand in hand with creative thinking about potential future profiles for international policy-relevant assessments and reports. To start the discussion, we would like to present some preliminary ideas for consideration.

First, environmental issues needing additional attention by the policy community should be highlighted. Based on an ongoing assessment of environmental trends, the (projected) state of the environment could be compared against reference values selected for each issue (depending on the phase of policy development, this can be one target value or a range of options). Issues and regions for which additional efforts - research, information gathering - are necessary, as well as the level of additional effort needed, could be identified.

Second, global assessment reports could present successes in environmental policy and implementation as illustrations of steps forward that can be made. By presenting successful and promising developments, collective action in the context of sustainable development can be enhanced. In addition, developments in partnerships, international coordination and funding can also be highlighted.

Third, significant trends in environmental pressures could be presented. These trends can be regarded as early warnings for future environmental trends, considering the time lapse between pressures and impacts at the global and regional level and the delay time of societal responses. The time horizon of this analysis could be 10 to 40 years.

Consequently, a global assessment report can have the following elements:

First, it would be based on an integrated analysis of trends in the state of the environment, as a function of demographic and socio-economic developments. Past trends and scenarios for future trends could be analyzed in order to compare the (projected) state of the environment to policy objectives. A relevant time-horizon in the analysis of these trends and scenarios would be 10 years, but it might be wise to include a longer term prognosis (10-25 or even 50-100 years, depending on the issue being considered), in order to allow for delays in societal and natural systems.

Second, the report can, in order to present feedback to governments and international organizations, present an appraisal of agreed international policies. It should also include the results of ex ante evaluations of alternative policy options, in order to identify promising strategic lines for environmental policies during the next ten years period.

In addition, the global report could address more specific target groups by including region specific and issue specific sections and by documents directed to donor communities. In order to support such activities, a well-organized world-wide network of excellent reporting and assessment institutes should be established. Possible directions for the activities of the network components are outlined in the following chapters.

CHAPTER 2

A FRAMEWORK FOR ENVIRONMENTAL REPORTING AND ASSESSMENT

2.1 THE FRAMEWORK

Most of the current regional and global environmental reporting systems are static and statistics-based. Information about the state of the environment is consequently limited to the past and present situation for individual themes. We propose to improve these systems by applying a set of - conceptual and computer - integrated models and associated indicators, supported by a broad network of international experts and expert institutions. We have adopted an *integrated and multidisciplinary framework* to guide the development of a reporting system that recognizes the dynamics of the interactions between human society and the environment at different spatial and temporal levels. We distinguish two main systems: the *human system* and the *environmental system* (figure 2-1). Within these systems we can further distinguish several subsystems . In figure 2-1, the human system is subdivided into a *social subsystem* - including demographics, health, education, equity, emancipation, safety - and an *economic subsystem* - including energy, production, consumption and trade, and stock of human (labour, capital) and natural resources (see Box 2-1 on natural resources). The environmental system is subdivided into the *biotic subsystem* and the *a-biotic compartments* proper: physical and chemical characteristics of soil, air and water. Alternatively, the environmental system could be subdivided according to environmental issues that have their influence across compartments (e.g. climate change, eutrophication, acidification).

From a systems analysis perspective, activities in the human system exert *pressure* upon the environmental system. As a consequence, the characteristics of the *state* of the environment change. This again causes functions of the environment to change: *impacts*[1]. Reacting to these impacts, the human system shows a societal *response*[2].

Figure 2-2 illustrates how 'pressure', 'state', 'impacts' and 'response' are coupled in a dynamic cycle. This generic approach is characteristic of most integrated environmental policy models. Of course, in the real world the interactions are more complicated than the simple sequential representation of figures 2-1 and 2-2, but we believe that the proposed framework can serve the important purpose of structuring and analyzing the most important interactions[3].

RELATING IMPACTS TO FUNCTIONS

In describing the 'impacts' resulting from changes in the 'state' of the environmental system, it is important to relate 'impacts' to specified functions. Where standards and guidelines have been set, a specification of functions has also usually been made. For fresh water systems, for example, a conventional breakdown of functions is: transport, hydropower generation, industrial supply, agricultural supply, fishery, drinking water preparation, recreation, support of ecosystems. Examples of functions of soils are: support of infrastructure, supply of materials, agricultural resource base, support of natural vegetation. Changes in these functions are of more direct importance to policy makers than changes in the physical, chemical or biological characteristics of the different systems.

Indicators are used to communicate information about the elements in the cycle in figure 2-2, their interactions and changes over time. The term 'indicator' refers in this report to a piece of numerical information that is both (1) part of a specific management process and can be related to the objectives of that management process and (2) has been assigned a significance beyond its face value. (Bakkes et al., 1994). Figure 2-3 illustrates how different indicators relate to the elements in the framework depicted in figure 2-1 and the phases of the dynamic cycle. Figure 2-4 shows

[1] The approach chosen here is very similar to the Pressure-State-Response framework as adapted by the OECD. In fact, the 'state' part of the OECD approach is here split in two parts to be able to accommodate information about changes in (impacts on) the functions the environment has for man (function changes). Most integrated models addressing environmental problems make this distinction. Also, for decision makers, functions of the environment are considered to be of more direct interest than the characteristics of environmental media and ecosystems.

[2] In systems analysis terms, 'steering' is also often used. It is replaced here by 'response' to acknowledge that the system under consideration is only partly steerable, as unintended 'autonomous' influences are also part of the response.

[3] 'Response' does not only include (impact-induced) policies, but also socio-economic responses resulting less directly from policy. In the proposed analysis, autonomous and policy-driven responses have to be clearly separated. Also, the one-way direction of the arrows is a simplification of reality. For example, responses can directly affect impacts, such as geo-engineering to counteract the enhanced greenhouse effect or cleansing of polluted soils.

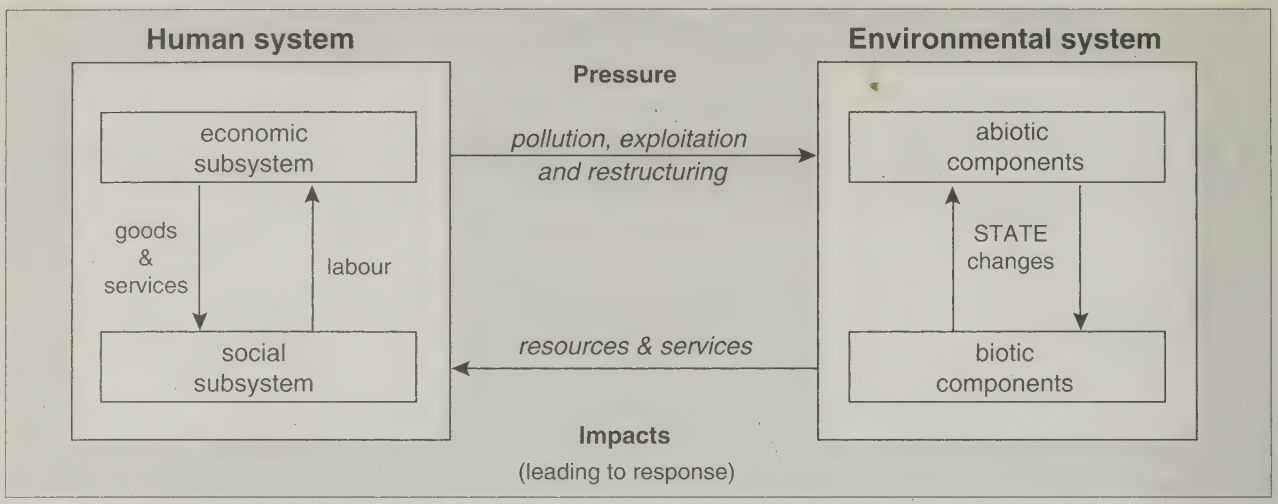


Figure 2-1: Framework for global environmental reporting

the result when Agenda 21 items are superimposed on this framework.

Using the above framework, this chapter discusses ways of using models and scenarios to support environmental reporting and assessment. First, in section 2.2 we discuss a systematic approach to assessing the past, current and future state of the environment as it relates to societal changes. Simulation models and scenarios are indispensable to this approach. The set-up of interrelated simulation models of varying levels of scale is discussed in section 2.3. Section 2.4 addresses the scenarios that can be developed and applied as important integrating instruments to support this assessment. Finally, in section 2.5 some aspects of the interface between scientific insights (c.q. models, scenarios) and policy processes are discussed. Chapter 3 then continues with a discussion on the role of indicators.

2.2 TOWARDS A STRUCTURED REPORTING AND ASSESSMENT METHODOLOGY

This study distinguishes between "reporting" and "assessment". An assessment adds expert judgement to reporting. An assessment includes the critical appreciation of available knowledge from observations and model results, and seeks to establish the meaning

Box 2-1: The position of natural resources in the proposed conceptual framework

It is usual to distinguish two different types of natural resources:

* non-renewable resources such as oil reserves and iron ore deposits;
* renewable resources such a forest resources and fish stocks.

In addition, some authors distinguish semi-renewable resources such as soil fertility and solar influx, but these semi-renewables might also be considered a sub-category of renewable resources.

Renewable and non-renewable resources can be represented either in the environmental subsystem or in the economic subsystem or in both. Although it is common to define non-renewables as economic commodities, and consequently represent them in the economic subsystem only, it is subject to debate whether this is an accurate representation.

Two viewpoints can be discerned. Defining non-renewable resources as economic commodities is in line with a functionalist perspective. In a strictly functionalist perspective, the depletion of non-renewable resources does not present any problem, since substitutes exist that may perform similar functions. An additional argument is that up to now the use of non-renewable resources has not been determined by the remaining stocks, but by their market price. As soon as their market price rises, these resources are regarded as scarce.

From an alternative viewpoint, it is the non-market functions performed by non-renewable resources that are taken primarily into consideration. In this perspective, the availability of non-renewable resources has some value in itself, considering they are part and parcel of the earth's ecosystem. Also, the depletion of non-renewables might present a problem in relation to future generations and their potential for fulfilling basic needs. From this viewpoint there seems to be no reason why future generations should not be entitled to some share in the remaining stocks of non-renewable resources.

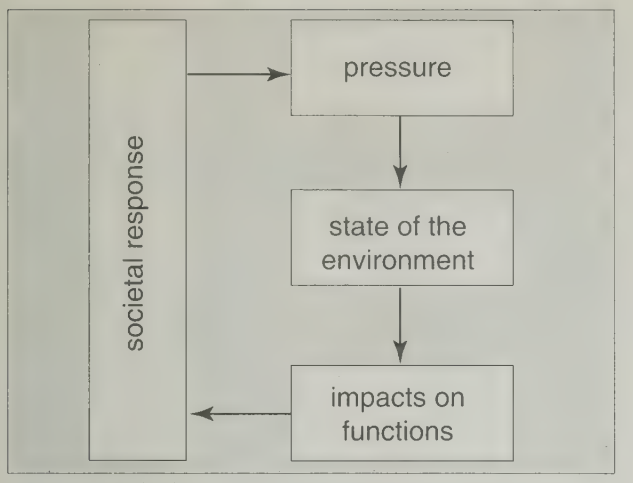


Figure 2-2: The dynamic cycle from a systems analysis perspective

of available knowledge in the light of policy objectives and uncertainties. The assessment can combine a scientific as well as a policy component. A *scientific assessment* describes the current state of scientific knowledge in policy-relevant terms. A *policy assessment* evaluates the effectiveness of established or proposed policies. Assessments can be targeted at a policy audience. The preparation of assessments forms an integral part of the reporting process and an important vehicle towards international consensus-building. This is in contrast with the more traditional assessments prepared by selected expert authors, which were not based on models and consistent forecasts but primarily on the judgement of a fairly limited number of experts about observations.

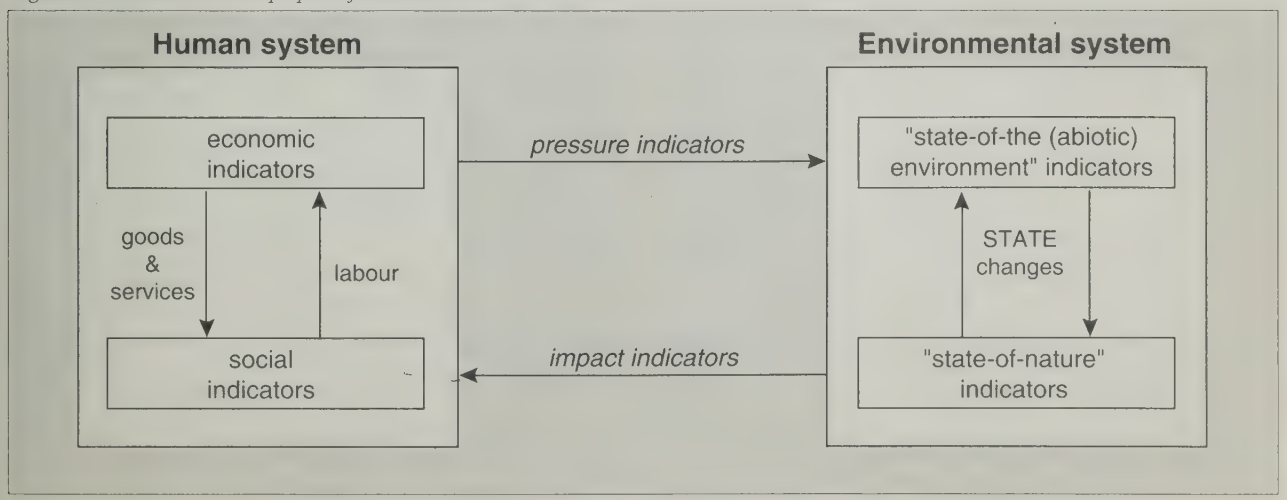
Simulation models can play a key role in the assessment activities. Assessment panels can formulate questions in, say half-yearly meetings. Thereafter, modelling teams (e.g. 3 to 10) could address the questions and report during the following meeting. This procedure has proven to be successful in support of the negotiations on the Long-Range Transboundary Air Pollution agreement in Europe (Hordijk, 1991). Models have been used in this way in a more ad hoc fashion in the proceedings of the Intergovernmental Panel on Climate Change (Swart, 1994). Models will be discussed in more detail in the next section.

The acceptance and impact of the produced reports can be enhanced by specifically facilitating consensus-building processes. In some cases (climate change, stratospheric ozone depletion, biodiversity) regular assessments are being or already have been institutionalized. However, no regular assessment system has yet been established for other important issues such as soil degradation and the quantity and quality of fresh water resources.

Although assessments about different individual environmental issues are essential, we argue that this is not sufficient. To capture the interlinkages between different issues in a coherent framework, a cross-cutting, integrated assessment is required also. But let us start by illustrating a possible structured reporting and assessment methodology for addressing single-issue environmental themes. It could have the following generic steps (based on an example for a river basin by Heij, 1994):

step 1. *definition of theme, system, problem and objectives*: before addressing the issue in detail, a clear definition of the issue has to be elaborated as a basis of further reporting and assessment activities; this includes an initial selection or development of models and associated indicators and reference values based on an evaluation of user demands.

Figure 2-3: Indicators in the proposed framework



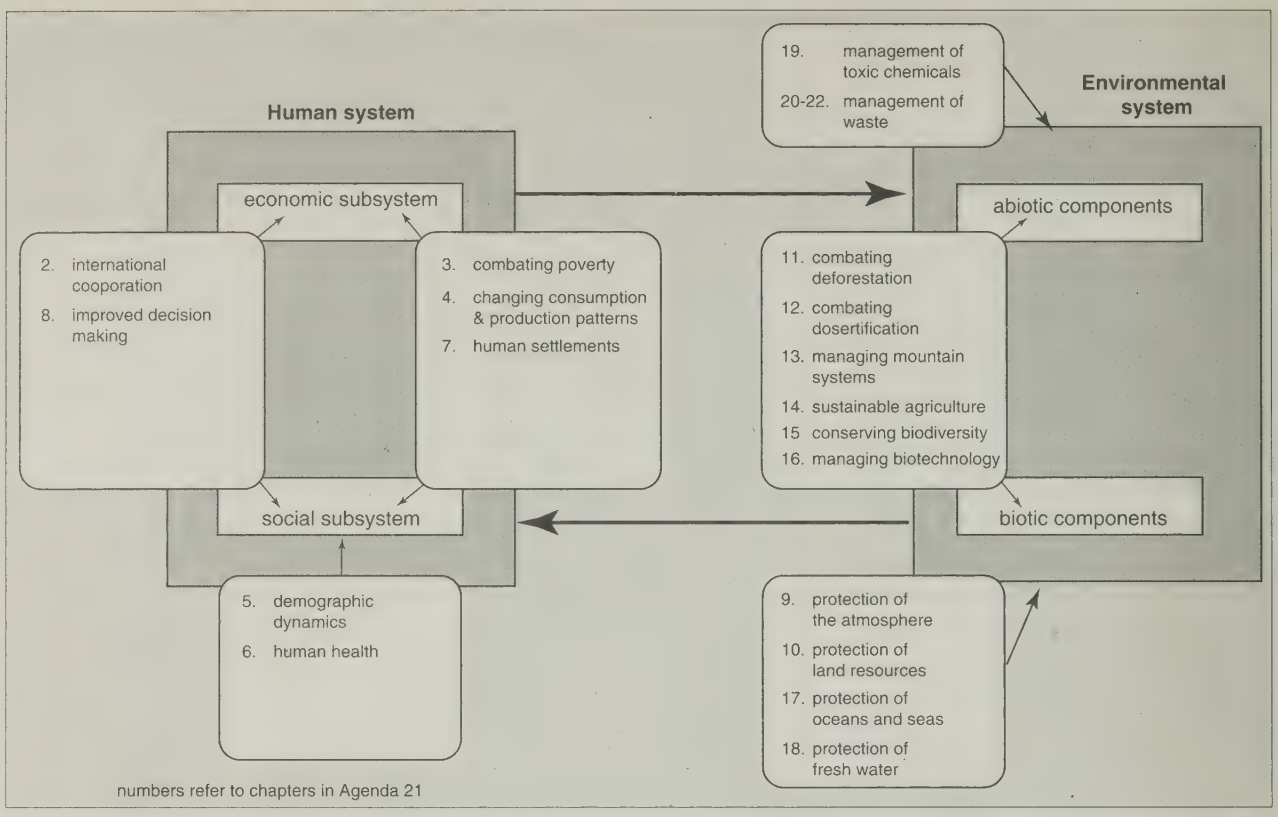


Figure 2-4: Agenda 21 and the proposed framework

step 2. *characterization of the stressed environmental system:* biological, chemical and physical aspects of the defined system (e.g. fresh water systems, urban air quality, climate, etc.) are inventoried.

step 3. *characterization of the socio-economic changes*: the socio-economic factors that determine the demand for resources associated with the system under consideration are identified. The selection of indicators and models is refined.

step 4. *diagnosis/analysis of the current stress on the system*: based on 2 and 3, an appraisal of the current situation is made, applying the models and indicators selected in step 1 and refined in step 3.

step 5. *prognosis/forecasting of the future stress on the system*: internally consistent sets of assumptions (scenarios) are developed to arrive at possible future developments of the system. Projections are developed with the available toolbox of models and comparisons with reference values of indicators made as a basis for the identification of emerging issues, for early warning, and for priority setting.

step 6. *analysis of interactions with other socio-economic and environmental factors*: the potential response options are evaluated with respect to their implications for other developmental and environmental issues.

step 7. *analysis of costs and effectiveness of planned and potential responses*: planned and potential additional responses are identified and characterized in terms of costs and effectiveness as a basis for decision making on optimal investment and management priorities.

Clearly, the simple sequential approach described here would in reality be a more complex iterative process, involving both scientists and policy makers. The proposed methodology could be applied at appropriate time and spatial scales. In a cyclic procedure, the approach would be repeated and refined as new information became available. This could imply a redefinition of the problem.

A fully integrated and comprehensive analysis would require the integration of step 7 into the whole process. A preliminary attempt to do this in a systematic fashion using models - notably the TARGETS framework - will be described in part II.

2.3 INTERLINKED MODELS AT VARIOUS AGGREGATION LEVELS

Models are tools for organizing knowledge at the proper time/space level. There are several advantages in using models in environmental reporting and assessment. These include:

1) *the dynamic analysis of the interactions* between the components of the global systems under consideration: the driving forces (e.g. population, industry, technology), the changing state of the environment, the impact on functions of the environment and the societal response to the changes;

2) *the development of forecasts and early warnings*: models allow for extending an analysis in time and space and implicitly show time delays in environmental and social processes and thus may lead to priority setting superior to priority setting without forecasting facilities;

3) *the optimization of monitoring systems*: models can help in optimizing investments in monitoring systems and can generalize patterns on the basis of incomplete data and allow approximations in data-poor environments.

Of these, the first two in particular are relevant to this report's proposals for a policy-oriented reporting and assessment framework; so it is to a discussion of the use of models in reporting and assessment that we shall now turn.

The regular use of models in diagnosis and prognosis of environmental changes is a rather recent phenomenon. In the past, large-scale models addressing - sustainable - development have been biased towards the socio-economic factors, as will be discussed in part II. However, increased awareness and understanding of environmental problems have spurred the development of more sophisticated models of environmental change, which have redressed the balance between the human and environmental systems. Environmental forecasting and assessment is now being applied extensively at the national level in a limited number of industrialized countries, one example being the Netherlands (RIVM, 1992). At the international level, it is being used on a regular basis in support of the negotiations about the Long-Range Transboundary Air Pollution agreement in Europe (Downing et al., 1993). On a more ad hoc basis, models have also been used for assessments in support of the negotiations of the Law of the Sea (Sebenius, 1981), the Montreal Protocol (WMO, 1985), and the Framework Convention on Climate Change (IPCC, 1990). Integrated policy models have been developed by a limited number of organizations that are either funded primarily by national governments, such as RIVM in The Netherlands (e.g. IMAGE) and Battelle in the United States (first and second generation Edmonds & Reilly models), or by international contributions through interested governments and foundations, such as IIASA (RAINS, world food models) and the Stockholm Environment Institute (POLESTAR).

Although a few models used in the analysis of global environment and development issues are already available, they often deal with selected individual environmental themes or focus on a limited set of socio-economic factors. To meet the objectives of integrated environmental assessments in the context of Agenda 21, the application of models within our framework will have to be extended to cover sustainable development strategies in general. It will also have to take full account of the linkages between environmental issues and between environment and socio-economic development at the global and regional levels.

While for some important issues, such as soil degradation, waste and loss of biodiversity, no appropriate models are available, most models that have been developed in the scientific realm are expert models focusing on elements of the causality chain for one particular issue. Sometimes, such models are adapted to serve policy purposes, but they may not be as useful for supporting decision making as those models specifically developed for the purpose (De Rond, 1994).

Furthermore, integrated models capturing the spatial levels between the local and the global remain scarce. In dealing with the issue of sustainable development, one has to take into account the variety of scales in space and time that are involved. Although models describing ecological processes at the level of large-scale vegetation zones or biomes, and at the level of individual species, to analyze the impacts of climate change on ecological systems are available, we do not know of any integrated model that has been developed to capture the important intermediate level of ecosystems. Clearly, we will need to develop purpose-built models adequate to this task. We would therefore propose an approach using a set of mutually supportive simulation models at different levels of scale. And because higher levels of scale usually imply higher levels of generalization, effective interaction between the development and application of modelling tools at different levels will have to be developed to ensure dynamic reporting about the past, current and future state of the environment.

On many issues, it is likely that the dynamic linkages can be explored by high-aggregation level models which, later on, when the relevance of the linkages has been assessed, can be adapted to the low aggregation level.

At the high aggregation level, the focus is on conceptualization and exploration of long-term dynamics. A recent example is the

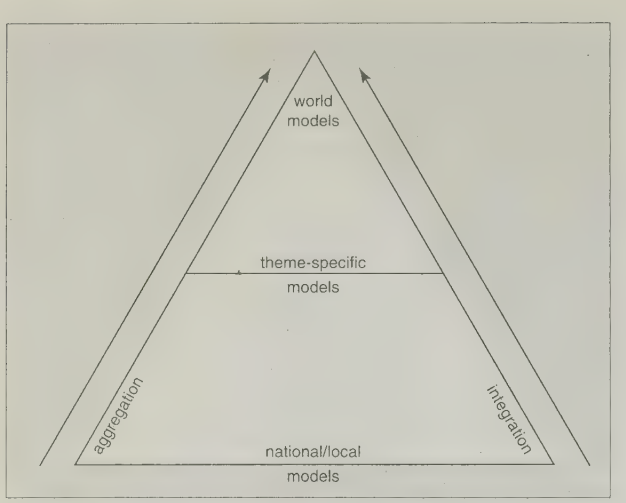


Figure 2-5: Different types of models for different levels of scale

TARGETS-model (Rotmans et al., 1994), which serves to explore the long-term, often speculative and to some extent inherently unknowable dynamics which may shape the world system over the next 100 years. It consists of submodels which are condensed representations ('meta-models') of coherent subsystems in the real world and these are continuously evaluated vis-à-vis more detailed and scientifically corroborated models. Examples of such submodels are a population/health submodel, an electric power generation submodel, a carbon-cycle and a stratospheric-ozone submodel. The various submodels are integrated in a transparent fashion into a larger framework. Provided that the submodels are well understood in their over-all dynamic behaviour, such an integrated model can be used to explore and illustrate the consequences of a variety of developments / scenarios in the human and economic world. It also serves as an exploratory context for the design of meaningful indicators as well as other conceptualization issues in the search for sustainable development strategies. Some features of the TARGETS model are illustrated in part II of this report.

The other way around, low-aggregation models can construct over-all relationships which may hold for larger regions or even for the world at large[4]. Such generic methodologies are used to refine the high-aggregation model. Figure 2-5 visualizes this set-up. However, many of these models can be used for multi-disciplinary reporting and assessment purposes as well, or can be adapted to serve these purposes. For subregional issues, generic modelling approaches can be applied to address subregional issues in a global or regional reporting system. For many issues, however, no appropriate models are available and would have to be developed. Evidently, a number of issues have very little predictability because of the incomplete knowledge or inherently chaotic and complex system behaviour. Nevertheless, the methodologies described above may help to increase understanding of these issues. The different interpretations of projections from the natural sciences (based on experimentally tested knowledge) and the social sciences (more of an exploratory nature) need to be taken into account (see also box 2-2).

Evidently, a highly-aggregated approach has some major drawbacks, a crucial one being the lack of regional/local specifics. How serious a drawback this is depends on the subsystems involved - and the questions one would like to have answered. For example, for a commodity like oil with an increasingly global free trade context, the depletion and learning dynamics of exploitation of the global resource base can be dealt with adequately at a global level. However, to deal adequately with the import- and export flows of oil and their impacts on economic performance, one has to go down to the level of - groups of - countries which can be considered as more or less coherent in their economic development. It suggests a disaggregation to the level of economically, politically and institutionally relevant actors[5]. On the other hand, some issues related to environmental and ecosystem developments - like the dynamics of land and water use - have a distinct local character.

Although it may be possible to describe larger units in terms of generic parameterized models, the regional and local characteristics will always play an important role both in a scientific and a communicative sense. Gradually, as more data and knowledge become available, the models can be filled in at regional and local levels. For many purposes, one would like to work with a GIS-approach with variable grid resolution with generic dynamic model representations parameterized at the grid-cell level[6]. The confrontation between different methodologies at different levels of scale enhances the understanding of the relevant processes in the assessment and can make uncertainties better understood and manageable.

[4] In practice, the integration of high aggregation models and low aggregation models may present some problems related to the differences between these types of models in terms of the objectives for which they have been developed and the associated time horizon and spatial levels they incorporate.

[5] This is being done in the Global Environmental Strategic Planning Exercise project (GESPE) presently under development at RIVM (de Vries et al., 1993).

[6] RIVM's IMAGE 2.0-model (Alcamo et al., 1994) applies a combination between geo-political regions for socio-economic driving forces and a fixed grid (0.5°*0.5°) for the terrestrial biosphere.

Box 2-2: Integration across disciplines: levels of reality

From the onset it is important to recognize the social and cultural diversity within the world community. On the one hand, the world appears to be growing into an ever more integrated whole with increasingly shared models (mental representations) of how it is developing. On the other hand, there is a strong feeling that local social, cultural, religious and economic identity and autonomy need to be preserved. The richness of such feelings will have to be respected and used if a sustainable development strategy is to be made effective. One way of putting this into perspective is the acknowledgement that we are dealing with various levels of reality. One may describe the underlying vision as a layered structure with the physical at the bottom and the mental at the top. Each discipline has its own realm of investigation along this axis.

At each level, the nature of human knowledge differs with regard to how it is acquired and how it is framed into concepts and theories. Whereas in physical and engineering sciences the emphasis is on repeated controlled experiments and rather strict falsification procedures, knowledge in the social sciences is inherently of a more hypothetical nature due to its limited feasibility of controlled experiments with its object of study. The relevance of this perspective is that it reminds us that the nature of our models and the way in which their results are interpreted are not, and cannot, be uniform. More specifically, it can be used to:

* allow an explicit expression of various cultural perspectives on global environmental change issues, and
* provide a context for fruitful cooperation between social and natural scientists.

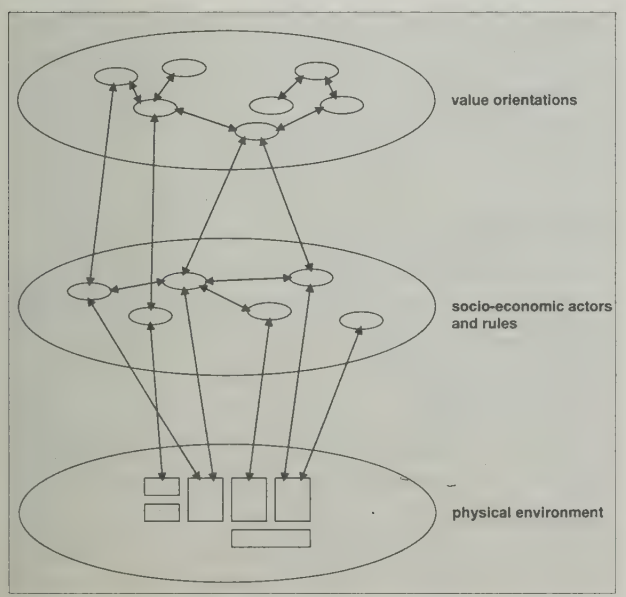
One could think of such a structure as being modelled at three levels (figure 2-6):

* a level describing the reservoirs and flows of the physical environment in which major principles of the physical and engineering sciences (e.g. mass balances) hold;
* a level at which quality and productivity are assessed (e.g. in monetary terms), which in turn are based on behavioural rules (e.g. investment decisions) and govern the major changes in the physical level;
* a level at which social and cultural values are represented which in their turn are the major frame of reference within which quality and productivity are evaluated.

How these different levels can be taken into account in systems of indicators is discussed in chapter 3.

The disaggregated approach has clear advantages in dealing with land- and water-related issues. Region-specific information can be used, impact assessments can be worded in fairly concrete terms and policy options can be explored at the proper response level. Since regional and local impacts are often the consequence of actions elsewhere, models can also have parts which are at much higher aggregation levels e.g. in the representation of atmosphere and oceans. Such models can, in turn, be conceived of as meta-models relating to the GCMs (Global Circulation Models). There are also a few drawbacks to a high level of disaggregation: simulations tend to be much more time-consuming and much more data-intensive, even to the extent that additional detail has negative marginal benefits because of lack of reliability and compatibility.

Figure 2-6: Representation of three levels of model realities: the physical world, societal actors and rules, and cultural values



In conclusion, we would argue that integrated models are necessary at the level of the globe, major regions or subregions (like water basins, agro-ecological zones, biomes). They should be complemented, where necessary and possible, by models that are only partially integrated and that capture specific issues in detail.

2.4 FORECASTING AND SCENARIO DEVELOPMENT

Models, as we have seen, can serve an important function in global and regional environmental reporting. In addition to allowing for analysis of cross-linkages between system components, they form the most important tools for the development and analysis of scenarios. Scenarios can then be used for early warning purpos-

es. To provide a coherent picture of potential future states of the environment as a function of human and natural driving factors, scenarios used should themselves be coherent and consistent. Ideally therefore scenarios used in a framework of integrated global environmental reporting and assessments should:

- be global with regional, subregional and sectoral specifics;
- be comprehensive, capturing quantitatively information about all ingredients of the different environmental issues and their interactions;
- be acceptable not only from a scientific perspective, but also from the point of view of decision makers from different regions;
- capture in a consistent fashion different interlinked sectoral developments;
- have clear objectives (input calculations of impacts for early warning, analysis of driving forces, evaluation of strategies, illustrating different perspectives) and associated selection of methodology and input assumptions.

Although different approaches are possible, we would propose a stepwise scenario development. First, a consistent set of global scenarios with regional detail would be selected or developed as a basis for all the analyses. In recent years, a large number of global scenarios has been developed to address the issue of climate and energy (see e.g. Morita and Matsuoka, 1994 for an inventory). The scenarios developed for IPCC (Leggett et al., 1992) are amongst the most comprehensive available. Although they are still too limited to address all relevant issues, they can nevertheless serve as the starting point for a wider range of issues. They typically include forecasts of population and economic growth by organizations like the World Bank and the United Nations. They also have some biases and inconsistencies (Coppock, personal communication). Identification of these deficiencies can form the basis for the development of new sets of scenarios.

Second, regional scenarios would be developed or selected for specific areas. These scenarios would preferably be based on regional studies, thus taking full advantage of regional expertise about the regional situation and priority issues. Attention has to be paid to preventing inconsistencies between the regional and supra-regional (global) scenarios. In the global as well as the regional scenarios, consistent assumptions on the development of relevant elements of the human subsystem would have to be included (e.g. energy prices). Scenario assumptions have to be selected for all subsystems of the proposed framework. Depending on the methodology used, the scenario parameters are endogenous or exogenous.

A typical approach to scenario development is the development of a "central estimate" (or "business-as-usual" or "conventional wisdom" scenario), complemented by different options for policy intervention, for example small technological changes or farther-reaching structural changes. Since the future cannot be known and since in different regions and in different sectors different perspectives exist on likely or desirable developments, it is unrealistic to strive for consensus on global or regional 'business-as-usual' scenarios. This is especially true for longer-term scenarios necessary to highlight the delays in the natural and socio-economic systems. It should be possible, however, to strive for consensus on a range of different scenarios as a basis for debate and analysis. While formal computer models can play an important role in devising consistent scenarios, the importance of unquantifiable factors for global and regional development - e.g. cultural, institutional and political issues - also require qualitative descriptions of possible futures.

The time horizon of the scenarios depends on the issue. For transparent and consistent reporting, some common future years would have to be selected. Again, the choice of these future years depends on the selection of indicators. To accommodate both long time lags in the environmental system and the shorter time horizon of investment programmes and tenures of decision makers, different time horizons would be selected (e.g. 10, 20-30, 80-100 and beyond 100 years).

2.5 MODELS AS INTERFACES BETWEEN SCIENCE AND POLICY DESIGN

There is much confusion about the role of models and scenarios in the interface between science and policy. Often, scenarios are misused as predictions, while model results are presented as reality. In fact, models and scenarios are just tools to structure discussions and analysis about processes that have a large degree of uncertainty. In this section, the role of models - and the scenarios designed with them - in the interface of science and policy is addressed in more detail. First, the crucial aspect of communication is discussed. Second, the role of different types of uncertainty is addressed.

ENHANCING COMMUNICATION AND CREATING LEARNING ENVIRONMENTS

To support international decision processes, it is important to explore how the insights incorporated in scientific models can be communicated adequately to decision makers. As will be discussed in chapter 3, appropriate indicators play an important role. In addition to communicating models and their results through oral presentations or through publications in scientific and policy documents, we believe attention should be paid to other means of communication. If models are to be used to their full potential to support decision-making processes, it is of paramount importance to develop learning environments in which their use is structured.

Although this is not the explicit subject of this report, we believe thinking about communication between researchers and decision makers *during* rather than *after* the development or models or the preparation of a report is of paramount importance.

Models can enhance communication between researchers and decision makers in various ways: from open-structured policy exercise set-ups to rigidly structured interactive-simulation sessions with potential users of the reports. The scope for creating learning environments has widened with the newly emerging computer hardware and software e.g. networking and multimedia. Visualization tools like innovative purpose-built software can be supportive in making models more transparent. Similarly, interactive decision support software can help to grasp the complexity of feedbacks, overshoots and time-lags. Such tools, in turn, can be called for within a larger learning environment in which participants are using techniques like backcasting and team-building. RIVM's GESPE-project (de Vries et al., 1993) focuses explicitly on this aspect of model use by creating a learning environment to deal with the dynamic complexity and social dilemma structure of the long-term impacts of global greenhouse-gas emissions. Teams representing major countries/regions in the world, are attempting to reach certain strategic goals for their region while being confronted with the long-term consequences.

UNCERTAINTY

The concept of uncertainty plays a key role in integrated assessment modelling, because forecasting the future pressure on, state of, and impact on the Earth's system as well as the societal response to these changes is beset with many uncertainties. In spite of these uncertainties decision makers have to outline environmental policies, because they cannot wait for total understanding and perfect models. In many policy-oriented models the imperfection and non-understandings are hidden. Addressing the issue of uncertainty is important in helping decision makers understand the big gaps in current knowledge. Therefore, it is crucial that uncertainties within integrated assessment models be made explicit and visible.

The concept of uncertainty covers many different cultural notions. Several attempts have been made to classify the different types and sources of uncertainties in models. Granger Morgan and Henrion (1990) distinguish three kinds of uncertainty in models: uncertainty about empirical quantities, uncertainty about the functional form of models and disagreements among experts. An alternative classification is the distinction of Funtowitcz and Ravetz (1989) in technical uncertainties (observations and measurements), methodological uncertainties (the right choice of analytical tools) and epistemological uncertainties (the conception of a phenomenon). For the purposes of this study the various types and sources of uncertainty mentioned above have been arranged in two categories, based on the subdivision of the Earth's system into the human system and the environmental system:

1. *scientific uncertainties*: those uncertainties occurring in the environmental system which arise from the degree of unpredictability of environmental change processes; they may be narrowed as a result of further monitoring, scientific research or more detailed/appropriate modelling;

2. *social and economic uncertainties*: those occurring in the human subsystem which arise from the degree of unpredictability of future geopolitical, socio-economic and demographic evolution and which are inherently 'unknowable' or in practice unpredictable.

Examples of scientific uncertainties include incomplete knowledge of the sources and sinks of chemical substances (gases), caused by lack of measurements, inconsistency of measurements, or deficient knowledge of the key physiological, chemical and biological processes. Illustrative of this is the inadequate understanding of the many feedback responses - both geophysical and biogeochemical - which can amplify (positive feedback) or dampen (negative feedback) the response of the biosphere system (Rotmans and den Elzen, 1993). There is thus a very high degree of inherent uncertainty in the whole complex system. Social and economic uncertainties, on the other hand, refer to processes in the human system, such as socio-economic, demographic and epidemiological developments, which are related to a set of behavioural rules and decisions. These rules and decisions are value-based and a major source of disagreement between experts, so their implementation in models is dependent on the actor's cultural perspective.

Disagreement among scientific experts is an important source of uncertainty in models. Although much disagreement arises simply from different technical interpretations of the same available scientific evidence, it is regularly complicated by the different perspectives people have. Relating the concept of uncertainty to the concept of cultural perspectives we arrive at the concept of perspective based alternative model routes, as a methodology to make uncertainties within the model visible (van Asselt and Rotmans, 1994). Figure 2-7 shows how different types of uncertainty can be related to different types of perspectives.

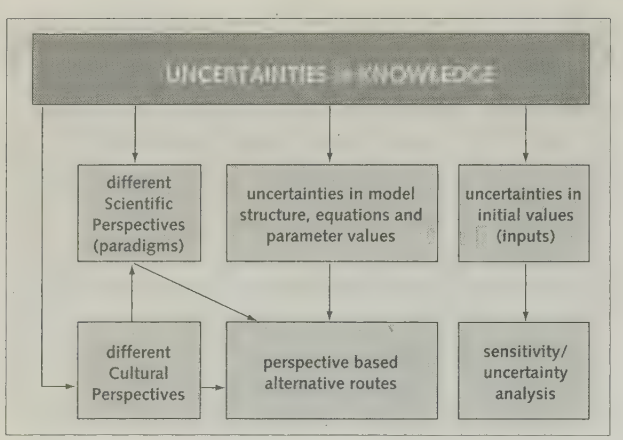


Figure 2-7: Different types of uncertainties

CHAPTER 3

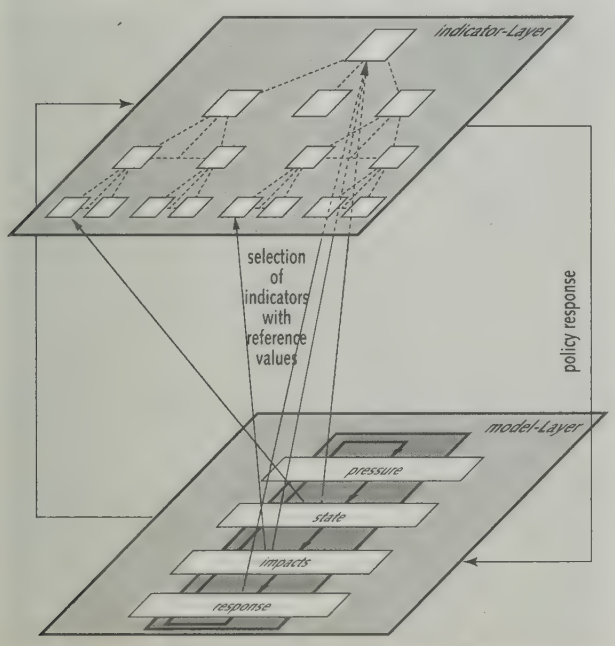
A SET OF INDICATORS

3.1 INTRODUCTION: THE RELATION BETWEEN INDICATORS AND MODELS

While models are important for supporting the analysis of the dynamic interactions of the different aspects of environmental change, indicators serve as the vehicles for communicating the resulting information. The term indicator as used in the context of this publication has already been defined in section 2.1. Paraphrased, the definition means that the comparison of an indicator with an objective or reference provides a signal for action or non-action. Model-based indicators (figure 3-1) are always complemented with information from other sources.

Of the several possible frameworks for developing and organizing environmental indicators, the two-dimensional matrix as applied by OECD (1993) and O'Connor (1994) would seem the most straightforward. The OECD framework places pressure, state and response indicators in columns, and each of 13 issues, such as water resources and acidification, in rows. In a recent Worldbank publication (World Bank, 1995) O'Connor has proposed a tentative adaptation to this matrix. By widening O'Connor's framework to include human and economic subsystems we would have a two-dimensional matrix capable of reporting sustainable development; see table 3-1.

Figure 3-1: The relation between models and indicators



This is further illustrated in figure 3.2 (which is an elaboration of figure 2.3). Each intersection between the human and environmental subsystems and the pressure-state-impact-response management cycle is characterized by an indicator, or, depending on the required level of detail, a hierarchical set of indicators. See 3.3 for an elaboration of this. However, it must be stressed that although this type of organizing framework is very helpful in facilitating comprehensive reporting, it will only provide a static picture because it omits the dynamic linkages between the indicators values.

3.2 CRITERIA FOR SELECTION AND DEVELOPMENT OF INDICATORS

We can distinguish between criteria that apply to indicators as a set, and those that apply to individual indicators. The proposed set of indicators for integrated environmental assessment and reporting should obviously match the framework proposed previously. This will require a balanced coverage of the population, economic, environmental, and ecological subsystems. The set will also have to cover pressures, state, impacts and responses, and allow for the presentation of the information in this form. Finally, the set of indicators should also be capable of measuring progress in attaining the long-term goals of Agenda 21 at the strategic level.

In addition, to meeting these criteria, individual indicators should also:

Be policy relevant

- Indicators should be tailored to the needs of the primary users (CSD, donor agencies, international organisations, national governments, major non-governmental groups etc.).
  Because indicators should be recognizable and understandable for client decision makers, stakeholders in the policy life cycle should be involved in their selection or development.
- Indicators should reflect parameters that are changing or can be changed by human intervention.
- It should be possible to relate the indicators to a target or

Table 3-1: "Sustainability Matrix" (World Bank,1995

ISSUE	AGENDA 21 CHAPTER			DRIVING FORCE		STATE		RESPONSE	
ENVIRONMENTAL		I							
Water	18	1							
Freshwater resources			i aa	*withdrawals/available		Water use/pop		Water charges/costs	?
			ab	Indus & Munic discharges	?	*Acidification	#	• % Waste water treated	?
			ac.	.....		•BOD or COD in water		.....	
Oceans & coastal zones	17		ii ad	*catches of marine species		*Marine spec./sustainable level	#	??????????	
			ae	km. coast/land area		*N&P in coastal waters	?	.....	
			af	.....		*Algae index	?	.....	
Land		2							
Land management	10		i ag	*Land use changes	#	*Human-induced soil degr.	#	*land management practices	?
			ah	.....		*Erosion index	?	.....	
Agric. & rural dev.	14		ii ai	Arable land/pop		Cropland as % wealth	B	Rural/urban terms of trade	
			aj	*Use of fertil.&pestic.	#	Area w/salin.&waterlogging		Extension service expend	?
			ak	.....		.....		Area of land reclaimed	?
Desert. & Drought	12		iii al	Fuelwood consumption/pop		*Desertification index	?	??????????	
			am	*Livestock/semi&arid land	#	.....		.....	
Other Natural Resources		3							
Forests	11		i an	Roundwood production		Forest area		Reforestation rate	
			ao	Deforestation rate		Stock of standing timber	B	Stumpage fees/world price	
			ap	.....		*State of biomass	?	.....	
Biodiversity	15		ii aq	*Rate of ext. of species	?	*Natural capital/km2	B	Protected area/land	
			ar	.....		*Threatened/extinct spec.	?	Protected/Sensitive area	B
Subsoil Assets	NA		iii as	Material balances/GNP	B	Subsoil assets% of wealth	B	*Prices of inputs/outputs	B
Fossil Fuels			at	Extraction rate(s)		Yrs. of proven reserves		Energy taxes/subsidies	B
			au	Energy consumption/pop		.....		Renewable/nonrenew res use	?
Metals & Minerals			av	Extraction rate(s)		Yrs. of proven reserves		??????????	
Waste		4							
Solid	21		i aw	Ind&Munic generation	#	Waste disposed/generated	#	Expend on waste collect, etc.	#
			ax	.....		.....		Waste recycling rate	
			ay	.....		.....		*Waste/GNP	?
Toxics	19,20,22		ii az	*Generation of toxics	B	*Area of land contamin.	?	????????????	
Atmosphere	9	5							
Greenhouse gases			i ba	CO2, SOx, NOx Emissions		CO2, SOx, NOx in atmosphere	?	Expand on Abatement	?
			bb	.....		.....		Signing of Intl. convention	
Stratospheric Ozone			ii bc	Prod. of CFCs, etc.		CFCs, etc. in atmosphere	?	Signing of Intl. convention	
SOCIAL	II								
Demographics	5	1	bd	Population growth (%)		Population Density		Fertility rate	
Education	16	2	be	School enrollment		Adult literacy rate		Education Exp./GNP	
Human Health	6	3	bf	Burden of Disease=DALYs	B	Life Expectancy		Health Exp./GNP	
			bg	Calorie supply/pop		Infant mortality rate		.....	
			bh	.....		*Env.-related diseases	?	.....	
Water Quality			i bi	Household water cons./pop		Access to safe water		%Pop w/sanitary services	
			bj	.....		Faecal coliform(no/100ml)		.....	
			bk	.....		*Lead, etc. in water	?	.....	
Air Quality			ii bl	*Pollution load	B	*Ambient concentrations	B	????????????????	
Human Settlements	7	4	bm	Urban pop % growth		%Pop in urban areas		Expend on hous.&public transp	?
			bn	Motor vehicles/pop		*Shelter index	?	.....	
			bo	.....		*Marginal settlements	?	.....	
ECONOMIC	III								
Poverty	2-4	1	bp	Equity (Gini coeff.)		GNP/GDP per capita ($)		Saving (adj.)/GNP	B
			bq	GNP/GDP %gr per capita		%Pop. in absolute pov.		Educational attainment	B
			br	*Prod&Cons patterns	?	.....		.....	
Financial resources	33	2	bs	Wealth/pop	B	Env. protection expend ($pc)	?	Investment/GNP	?
			bt	.....		.....		Env. taxes+subs. as %rev.	?
			bu	.....		.....		New ESD funding	?
Transfer of technology		34	3						
Productivity			i bv	Efficiency=NNP'/Wealth	B	NNP'/EDP1 per capita ($)	B	Intermed. Inputs/GNP	B
			bw	Unemployment rate (%)		Manufacturing/GNP		Capital/Output ratio	B
			bx	.....		Export concentration ratio		.....	
			by	.....		*Natural disasters index	?	.....	
INSTITUTIONAL			IV						
Decision-making str.	8,38-40	1	bz	????????????		*Mandated EIA, etc.	?	*Ratif. of intl. conv.	?

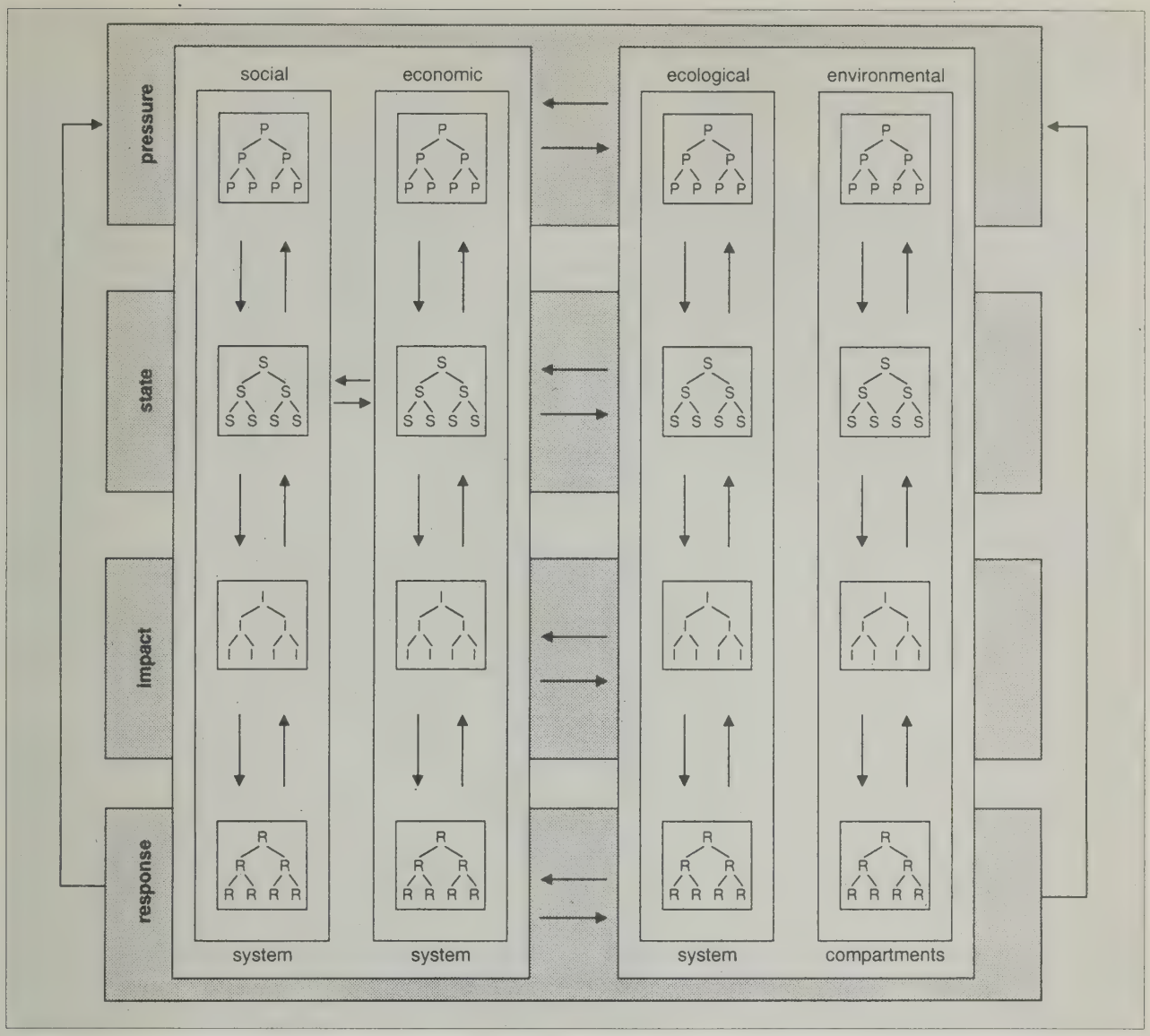


Figure 3-2: Pressure-State-Impact-Response indicators in the proposed framework

other reference value: is the situation getting better or worse and is it acceptable?

- The set of indicators should permit regional priorities to be addressed.

Permit forecasting

- The indicator definition should allow for plausible forecasts based on economic and demographic scenarios and policy options.
- It is important to realize that current knowledge does not allow us to link all indicators dynamically through integrated modelling. Knowledge of existing causal relationships between the human and the environmental system, as well as of relationships between various elements within the environmental subsystem, is limited. Nevertheless, we do think that a gradual transformation of the current system of static indicators into a dynamic system of mutually dependent policy-relevant indicators, is feasible.

Be built on existing environment and policy monitoring systems

- Indicators should be compatible with existing data sources and existing or evolving indicator efforts (e.g. in UNDP, OECD, WHO, World Bank, UNSTAT, World Resources Reports, etc.) as much as possible.
- Although the reporting and assessment described here is different from the regular and frequent monitoring of policy performance at the national level, or in the context of international agreements on specific topics, it should still be able to

relate indicators from the global integrated assessments to those used in performance monitoring. This is yet another reason why indicators in integrated assessments should be built on conventional definitions and classifications where possible.

As figure 3-3 illustrates, demands on indicators - to be measurable, policy relevant and usable for forecasting - do not necessarily coincide. Consequently, compromises on each of the three groups of criteria will have to be accepted. The limited availability or access to data will constrain the choice of indicators probably more than the limitations imposed by model-building. One of the issues which will have to be addressed is, how the 'top-down' proposed framework of models and indicators can be reconciled with the 'bottom-up' reality of available data and statistics, and the requirement of shaping transparent and accessible reports. And it is for this reason, amongst others, that we believe that global and regional pilot studies will be indispensable in choosing an adequate set of indicators.

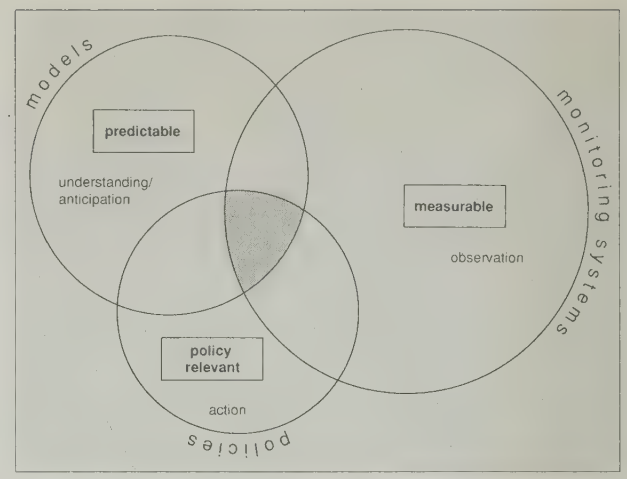


Figure 3-3: Criteria for the selection of indicators

3.3 TYPES OF REPORTING

Like the hierarchy of models, discussed in section 2.3, the associated set of indicators for global and regional reporting will have different levels. In particular, indicators can be selected, developed and organized according to:

- the degree of spatial generalisation; and
- the degree of thematic generalisation.

The term 'generalisation' is used here to refer collectively to all methods by which bits of specific information, valid for a specific case, issue or territory, can be used at a more general level of meaning. *Aggregation* - adding up, weighted if necessary - of specific bits of information to form an indicator is one possible way. Another way is *selecting* the most representative parameter - which is a somewhat special case of aggregation, assigning zero weight to all parameters but one (O'Connor, 1994). Alternatively, characteristics of a *frequency distribution* (such as: average, 95% percentile) can be used as the more general indicator. (See further under spatial generalisation.)

SPATIAL GENERALISATION

While the proposed system framework and two-level indicator system (see below) are applicable at all geographic levels, many environmental problems are either of a local or subregional nature. Also policy makers, for whom the assessments are made, are generally organized in institutions at different geographic levels: nations, (sub)regional economic and political organizations and global and regional United Nations organisations.

Reporting at spatial levels of generalisation higher than the original data requires clear protocols for data-reduction. Examples are:

- o *classification*: develop categories for indicators and report about the frequency distribution over the categories (for example, the surface areas in different soil degradation classes);
- o *exceedances*: relate the value of indicators to reference values at a low level of aggregation and report about the level of exceedance (e.g., the proportion of the region where the critical loads for acidification are exceeded by 5% or more of the surface area, calculated in grid cells of 1/2 x 1/2 degree);
- o *selected examples*: report about cases that are striking, or for which information happens to be available. Clearly, this rather arbitrary last option is a fall-back position if other methods of generalisation are infeasible.

THEMATIC GENERALISATION

Two levels of thematic generalisation can be distinguished:

- either highly aggregated or composite indicators at the systems level, designed to capture different elements in the causality chain or different environmental themes at the same instance (level A);
- less integrated, single-issue indicators, focusing on individual environmental themes
  (level B).

Level A: highly aggregated, multi-issue indicators. Aggregation or grouping individual indicators has advantages and disadvantages. The major advantage is the indices' synoptic character, often in the form of a dimensionless number (an index). The availability to decision makers at national and international level, of a 'simple' environmental index comparable to the economic Gross

Domestic Product (a highly aggregated index) and the socio-economic Human Development Index (a composite index; e.g. UNDP, 1993) would facilitate policy making in the broader context of environment and development. However, the use of aggregate indicators has several disadvantages, among which are the loss of analytical power and the complexity of the link between the resulting index and the real, observed world. An example of the loss of analytical power is the masking of the deterioration of one environmental problem, say greenhouse gas emissions, by the mitigation of another one, e.g. sulphur oxide emissions. In addition, aggregated indices may be relatively insensitive to variations over time.

A further point of possible criticism, especially with regard to indicators, is that the index value and its rate of change are dependent on the scaling and the weighting factors applied. Hope et al. (1992) claim that their national environmental index is largely independent of the origin of the set of weights (within Western Europe, that is). However, since their primary basis for weighting is public opinion and since this could be influenced by the publication of the index values, also with respect to the relative importance of environmental issues, this proposed weighting system does not seem to be satisfactory. Others have used expert judgement or delphi techniques. Another possible solution might be to assign a different basis for weighting such as the difference between the value of the thematic components in the highly aggregated indicator and their target values ('environmental deficit').

Notwithstanding the attractiveness of aggregated indices, separate single-issue indicators are indispensable for a number of reasons (such as specific environmental policies and comparison over time and between different contexts) . If we also note the time required before an aggregated environmental index is developed and accepted, then it is apparent that, irrespective of the state of the art, there will always be a need for a mix of both types of indicators to inform policy development. There is, therefore, a need to develop aggregated or composite indices (level A) at the same time as developing a more theme-oriented set of single-issue indicators (level B).

Level B: single-issue indicators. Possibilities for level B indicators range from selected single parameter indicators to composite indicators. Single indicators are a pars-pro-toto, a surrogate representative for the full issue. The classical example is sulphur dioxide emissions representing the issue of acidification.
Composite thematic indicators are developed by aggregation across substances (e.g. into acid equivalents, or biological oxygen demand), by aggregation across the causality chain, or by aggregation across environmental compartments. Aggregation across the causality chain has the specific purpose of compensating for the natural and societal delays along the pressure-state-impact-response cycle, which may be several human generations.

Traditionally, level B *indicators* are grouped according to specific *themes* or *issues*, e.g. 'economic development' or 'demographics' in the human system, and 'climate change' or 'eutrophication' in the environmental system.

Because all indicators are designed to meet a specific need, they have to be developed with this specific need in mind. This applies equally to levels A and B. Moreover, the choice and role of indicators are dependent on the phase in the policy life cycle of the issue under consideration (Bakkes et al., 1994)[1]. While one type of problem may be served by highly aggregated indicators more detailed indicators may be appropriate for issues in the later phases of policy development and implementation, such as performance monitoring[2]. Sets of indicators, therefore, will evolve along with the user needs.

3.4 REFERENCE VALUES

Reference values are here defined as the desired numerical or nominal values of indicators. Although these values are value-laden and often used for policy making, they need not necessarily be actual policy targets, that is linked to a set of policy measures and to be reached within a defined time-frame. Reference values can, in some cases, be based on a presumed "natural" or "original" state (number of species, concentration levels). Their primary function is to put the descriptive information on pressures, states, impacts and responses communicated through indicators into perspective. Without adequate reference values it is difficult to attach a meaning to changes in pressure, state, impact levels etc. It might even be impossible to discern between those trends that should be valued positively and those that should not. The 'dis-

[1] For instance, the model-based mapping of the exceedence of critical loads for acidifying deposition that is carried out in support of international environmental policy in Europe relates to the vulnerability of forest soils. In preparation of international policies with regard to acidification in Asia, critical loads have also been compiled. The Asian indicator relates to the vulnerability of 14 soil-vegetation combinations, including wet rice fields. While the European and Asian indicator systems use slightly different criteria, they may be used to compare levels at which critical loads are exceeded.

[2] In the profusion of indicator terminology, 'performance indicators' are sometimes understood to be distinct type of indicators. In fact, they are not. However, as it makes more sense to measure the environmental performance of a policy regularly once the issue and the policy have been defined operationally, performance monitoring correlates in practice with the use of the type of indicators that are relatively easy to measure and lend themselves to a straightforward comparison with an established policy objective, or the score of other countries in the region. (For examples, see Adriaanse, 1993 or OECD, 1993.)

tance' between current - or forecasted - environmental conditions and the desired situation or time-path is measured[3] . Two other functions of reference values are: to facilitate comparisons across environmental issues and to aggregate across related sub-issues.

If the reference values are to function properly in the context of our proposed framework, they will have to meet certain well-defined criteria. Several criteria are relevant. First, the reference values should be combined with the developed set of environmental indicators. Since no international set of indicators has been established yet, we can only state that the reference values should conform with the pressure-state-impact-response framework and the criteria that have been formulated for the selection and development of indicators (section 3.2).

Second, reference values should ideally be both scientifically robust and politically acceptable. Scientific robustness is important in view of the complexity of the environmental system and the need to monitor those elements, processes and parameters that are critical, typical or representative of this system and its subsystems. Political acceptability is important too because the combination of indicators and reference values is a tool to support to strategic international environmental policy setting and implementation.

Third, the reference values should refer to spatial levels that make sense both in terms of the policy processes to be supported and in ecological terms. They should therefore be spatially-independent, or relate to the international, the regional and the national level, and reflect the different situations in different parts of the world.

Fourth, reference values should be either time-independent, or refer to a definite time-horizon. They should allow decision makers to appraise progress being made towards the (long-term) objectives of Agenda 21. Although the time-horizon of separate reference values may vary according to the environmental issue at stake, the time-horizon addressed in the assessment itself should not exceed a period of time equal to one or two future generations.

Finally, reference values for various environmental indicators should ideally be based on an integrative and comprehensive notion of the environmental system. Formulating separate reference levels for separate environmental issues implies neglecting the interrelations between issues. Since the environmental system is a dynamic system characterized by interdependencies between the subsystems and its processes, neglecting these interrelations could well result in shifting rather than reducing environmental problems.

As an example of the type of reference values we mean, a sample of the reference values in use or proposed internationally for specific issues, is discussed below (Weterings and Smeets, 1994; see table 3.2 and part II chapter 5). This sample focuses on target values. Obviously, 'weaker' forms of reference values are also applied. For instance, the OECD uses averaged values for OECD countries as a benchmark when presenting indicator values for non-OECD countries. The main types of reference values found by Weterings & Smeets are, in decreasing level of supporting knowledge or acceptance:

(1) internationally accepted policy targets laid down in international agreements and conventions;
(2) values suggested by scientists, NGO's or international organisations, e.g. for use in performance evaluation;
(3) tentative approximations of sustainability levels.

Type (1) reference values appear more frequently in the pressure column. This was to be expected: driving forces excerting pressure upon the environmental system are relatively to direct monitoring and interventions, and therefore pressure-targets provide a good basis for policymaking. Type (3) values can ussualy not be defined so easily. Moreover, they reflect the impacts of different stress factors that can often not be distinguished in any precise manner. Therefore, state parameters (2) are often applied as a kind of "environmental quality standards". The response column is almost empty: the table is based on selected cases of *international* reference values, and it is usually left to individual countries to decide *by*

Table 3-2: Reference values for selected environmental issues

	Pressure	State	Impact	Response
Climate change	1, 2, 3	1, 3	3	
Ozone depletion	1	2		
Acidification	1, 2, 3	2, 3	3	
Water resources (marine)	1			1
Water resources (river)	1	2		1
Fish resources	1, 2	2		

1: international policy targets, accepted by governments
2: values suggested by scientists or NGO's, e.g. for use in performance evaluation
3: tentative approximations of sustainability levels

Source: Weterings and Smeets, 1994

[3] Indicators for the human system should also have reference values in order to judge if they are developing in the right or wrong direction. However, in this report we focus on reference values of environmental indicators only.

what means an environmental objective is to be attained. It should also be noted that *costs of the necessary measures*, which could have featured in the response column, is usually not quantified in international agreements.

3.5 VISUALIZATION

Because of the complexity of integrated assessment models and the information these models produce, it is crucial to use appropriate visualization techniques. Modelling and visualization software for integrated assessment models is being developed. We believe the use of such software will:

- make the models as transparent as possible;
- make the underlying theories as clear as possible;
- increase the quality of models by opening them up to easy inspection by users;
- increase the use of models by decision makers by providing easy-to-use interfaces;
- enable the user to change parameters, variables, functions and scenarios in an interactive manner;
- display uncertainties and complexity of the systems behaviour comprehensibly.

Apart from the traditional and mostly static techniques for visualizing information such as diagrams, graphs, tables and histograms, such software will include innovative techniques that will allow an interactive, comprehensive and dynamic presentation of information.

Various aspects already emphasized in the present report, would ideally be incorporated in the visualisation. These would include:

- o development over time;
- o comparison with (indicators) reference values;
- o insight in delays and cross-linkages in the PSIR cycle;
- o understanding of cross-linkages between different issues;
- o indication of reliability of the information.

There are different ways of working towards this, all of which have their particular advantages and disadvantages. In an indicator vector, different aspects of the causality chain can be combined into an aggregated index (Rotmans et al., 1994). For instance, the complex problem of stratospheric ozone depletion may ultimately be described by a vector of three indicators: production of CFCs (pressure indicator), change in atmospheric chlorine concentrations (state indicator) and relative change in skin cancer incidence (impact indicator) (den Elzen, 1993).

Visualizing the multi-dimensional components of indices might

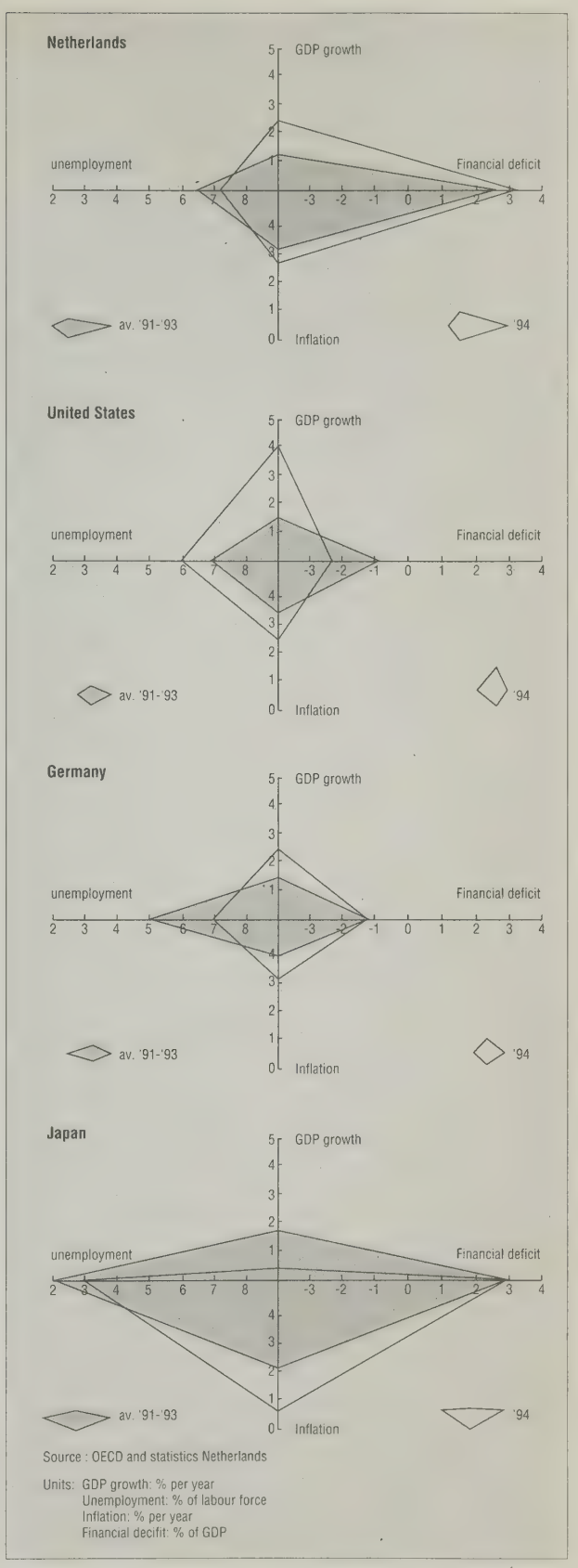


Figure 3-4: An example of a multi-dimensional index: the economic performance of four countries (average 1991 - 1993)

be an alternative to the sometimes indigestible, highly aggregated indices derived through scaling, weighting, and aggregation procedures. In developing an indicator framework this means that at all levels of the hierarchal framework, a choice can be made between aggregation/selection and visualization. While aggregation or selection aims at reducing multidimensional information to a one-dimensional indicator, visualization helps us to represent more dimensions in one picture. An example of a visualization technique representing four indicators of the economic performance of national economies (GNP, unemployment, inflation and financial deficit) in a two-dimensional form is presented in figure 3-4. The picture shows that Dutch economy during the period 1988-1992 fared better than in the year 1993. The same technique is used to compare countries.

In general, more-dimensional representations include more information about linkages and interactions between different components, but the resulting pictures may be more complex and need more explanation. On the other hand, modern visualization techniques facilitate the provision of linked information in a concise way, without loss of essential information about interlinkages or developments over time. Modern communication techniques thus transcend the limitations of the two-dimensional book. This, together with the wide availability of computers, may justify the development of a visualization package to accompany the printed reports.

PART II

THE SUBSYSTEMS

CHAPTER 4

MODEL AND DATA REQUIREMENTS

4.1 FEASIBILITY OF AN INTEGRATED MODELLING APPROACH

Within the framework of this report, no comprehensive overview of past and current modelling efforts in the world can be attempted. However, illustrations are given at various levels of aggregation and integration. In this section we briefly describe selected examples of models that attempt a balanced *integration of the environmental and human systems at the global level.*

Models that attempt to set the human and the environmental system on an equal footing are rare. The main wave of global modelling efforts followed the publication of 'Limits to Growth' in the early 70s (Meadows et al., 1974), based on the Forrester/Meadows systems dynamics model[1]. The Mesarovic and Pestel (1974) model addressed regional interdependency and was intended to serve as a policy assessment tool. The Bariloche model (Herrera et al., 1976) added the South's perspective to the discussion, focusing on quality of life and a different global order. Other global models addressed a subset of problems, e.g. MOIRA (Linnemann et al., 1979), focused on food and hunger. The FUGI-model (Kaya et al., 1977), SARU (SARU, 1978) and the United Nations Global Model (Leontief et al., 1977) focused on the world economy, including the problem of resource depletion, which was a key concern in the seventies. However, environmental issues other than resource depletion were addressed in a fairly simplistic fashion.

Few new efforts have been undertaken since this 'first decade of global modelling'. At the Berlin Wissenschaftszentrum, the GLOBUS model, incorporating the economic and political aspects of world development, was developed (Bremer, 1987). The Basic Linked System, developed at IIASA, followed from the MOIRA efforts and described the world's agricultural (trade) system in more detail (e.g. Fisher et al., 1991). All these global models focused on the social and economic components of the human system. Since the seventies the knowledge about, and the political importance of, environmental issues has increased considerably. This has allowed for a more balanced treatment of the human and the environment system in both science and policy. The linkage between environment and sustainable development is now fully recognized in environmental research and modelling. This is reflected in a number of new global modelling efforts complementing the thematic models and integrating their results. Among these is the POLESTAR model of the Stockholm Environment Institute. This includes information on large numbers of components of the human and environmental systems in an information system incorporating scenario features (Raskin et al., 1994). It is being deliberately kept simple. Recently, at RIVM a new effort (TARGETS) has started, which will take into account the latest developments and knowledge from the environmental, information and socio-economic sciences in analyzing the implications of sustainable development in an integrated and dynamic way (Rotmans, et al., 1994).

TARGETS is intended to be used to perform an analysis and assessment on a global scale of the quantitative and qualitative linkages among social and economic processes, biophysical processes and effects on ecosystems and humans from an integrated system dynamics perspective. Common causes, mechanisms and impact of a number of coherent themes, functions and scales are translated in terms of Pressure, State, Impact and Response. The TARGETS-model can be represented as a two-dimensional integration matrix (figure 4-1) in which the vertical "rows" integrate the cause-effect chain of an issue or theme and the horizontal "rows" the integration of cross-linkages and interactions between various pressures, various state-dynamics and various impacts. The time covered by the TARGETS model will span about two centuries starting from 1900, symbolizing the end of the pre-industrial era, until the end of the next century.

4.2 DATA MANAGEMENT FOR INTEGRATED ASSESSMENT AND REPORTING

Data provision is essential if the proposed approach is to be applied in a balanced way to the different regions that make up the world. Moreover, data provision is by far the most resource-consuming element in the reporting process (UNEP, 1993).

One important component of the data demand of integrated assessments relates to the driving forces of environmental change, such as agricultural practices, demographic developments, land

[1] An excellent overview and a critical evaluation of the models developed in the seventies is given by Meadows et al. (1982). We refer the reader to Meadows et al. (1982), and more recently Rotmans et al. (1994), for a discussion of the advantages and limitations of this generation of models.

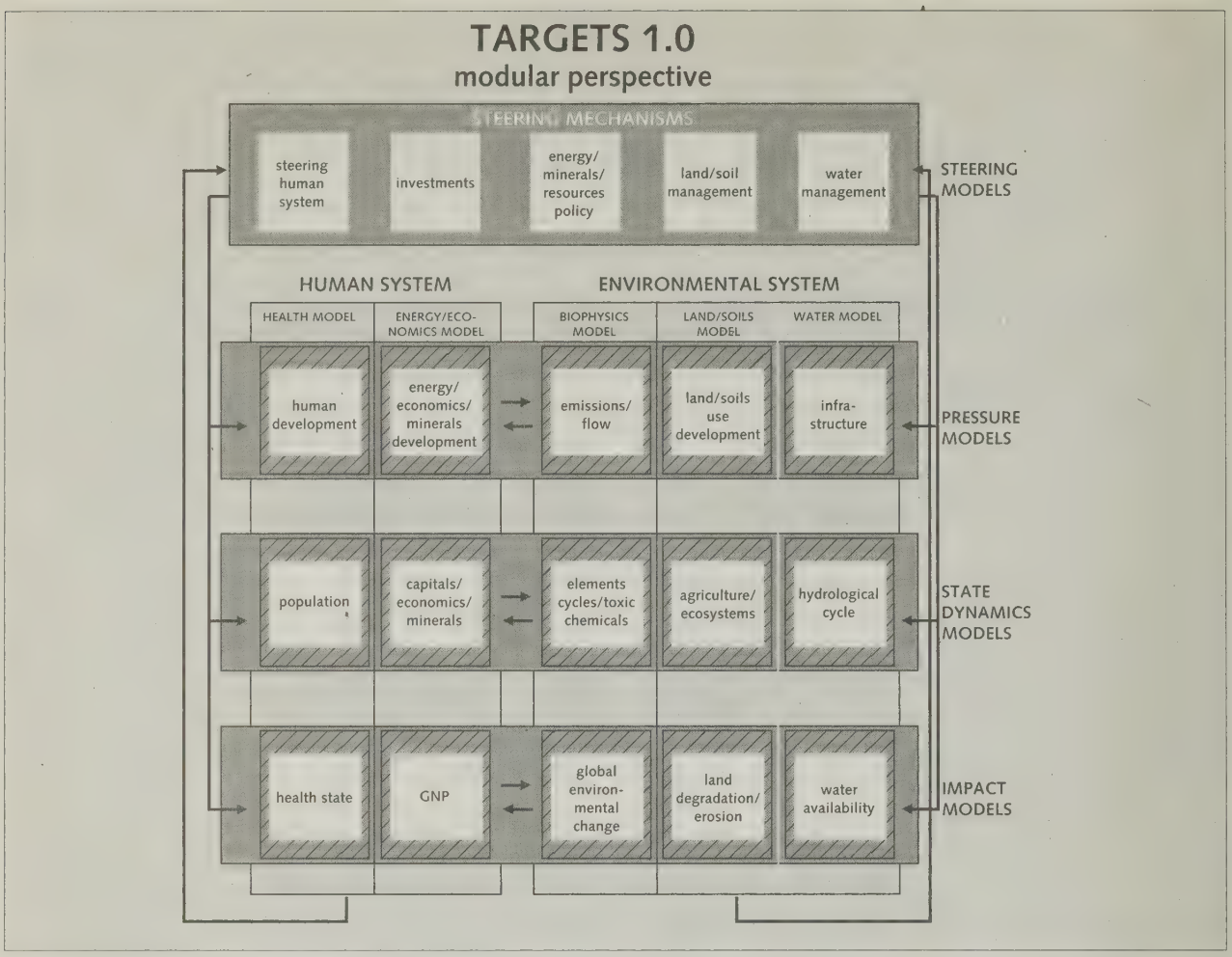


Figure 4-1: TARGETS - a fully integrated model of the global dynamics for the analysis of sustainable development (under development), (Rotmans et al., 1994)

use, energy, transport, etc. (Bakkes, 1991). This underlines the importance of statistical offices and sources of other socio-economic data sets for UNEP's new reporting and assessment.

In many cases environmental pressures and changes need to be analyzed in a geographically explicit manner. However, different spatial breakdowns may be operating between the human system (administrative units such as countries and clusters of countries), environmental pressures and environmental state (often gridded systems), ecosystems and natural resources (often geomorphological units, such as drainage basins). Additionally, administrative, ecological and gridded spatial units may represent different information layers that may not be compatible (O'Connor, 1994). A clear data management strategy is necessary in order to bridge these differences. Moreover, because harmonization of classifications and definitions is such a time-consuming process, action will be required relatively soon (Bakkes, 1993). One possible data management strategy would be to collect and calculate data on the physical environment at such a high resolution that these data could be aggregated to the country level.

Because integrated environmental assessment and reporting addresses changes over several human generations, intertemporal comparability of data needs to be safeguarded. Because of this, care has to be exercised to embed the responsibility for core data series in stable institutions, and to make use - as far as possible - of multi-purpose, long-life time series. Experience at country and regional level shows that a substantial part of the data needs for integrated reporting only becomes clear during the collection process (Bakkes et al., 1991). The complexity of the study is certainly a factor here, but no less the explicit aim of scientific convergence and tuning of the study to the needs of the users. Therefore, we believe a flexible data retrieval service is required as a supportive element for integrated environmental assessment and reporting system, in addition to its more regular sources.

CHAPTER 5

AN INTEGRATED APPROACH TO THE ENVIRONMENT SYSTEM

5.1 INTRODUCTION

Over the last decades, pressures upon the natural environment have grown rapidly. As a consequence, many stresses on the environment are approaching threshold levels of sustainability or may have already exceeded these. Environmental degradation is already visible around the world, while further degradation due to current and future human activities is expected in the future. These problems are occurring at increasing scale levels. Population growth is an important driving force. From the economic perspective, both wealth - through growth of material production and consumption - and poverty - through inequitable distribution of this wealth - are among the key driving forces. The relationships between these factors and environmental degradation are complex, and will be discussed in chapter 6. In this introduction, we discuss the importance of integration, system delays and the different perspectives on priority issues.

IMPORTANCE OF INTEGRATION

Hitherto, environmental issues have usually been categorized, taking the environmental compartments air, water and land as a starting-point. Monitoring, research, and policy development have followed this thematic approach. In many instances, where easy, cost-effective technological mitigation options have been available, this approach has proven valuable. However, (1) the complexity and interdependency of environmental problems (such as global warming and stratospheric air pollution) require a different approach; (2) more localized, but universal problems (like the degradation of the quality of soil, water and air) are pervading the world; and (3) easy single-issue solutions are becoming less effective. Therefore, a more integrated approach is becoming inevitable. It has already been argued that such integration should not only be across the cause-effect chain, but also across different interacting environmental issues and across the linkages between social, economic and environmental changes. The approach proposed in part I of this report combines:

a) *thematic reporting and assessment*: the current practice of addressing individual environmental problems on an individual basis should be enhanced by structuring a reporting and assessment methodology in such a way that it takes into account the different elements of the environmental (pressure-state-impact-response) management cycle;

b) *global and regional synthesis*: complementary to thematic reporting and assessment, methodologies should be developed to integrate the global and regional social, economic and different environmental changes: multi-impact driving forces, multi-stress impacts and multi-purpose responses.

SYSTEM DELAYS

Crucial characteristics of environmental changes are system delays and accumulation. Many environmental systems have a natural buffer capacity. While stresses pile up and environmental thresholds are approached, impacts are not immediately observed. This type of delay often amplifies existing delays within the human system in responding to changes in the environment, such as the time needed for awareness building, policy formulation and negotiation, implementation of technical or organizational measures and the turnover rate of existing capital stock. Knowledge and forecasting is essential in order to identify environmental problems in time to allow for corrective action. While economic assessment and forecasting is usually limited to the short term and economic indicators have a turnaround time from weeks to years, environmental assessment and forecasting often has to apply time horizons of decades or centuries in order to capture system delays. Different environmental problems have different time horizons, varying from hours (e.g. health effects from local air pollution) to centuries (stratospheric ozone depletion).

DIFFERENT AND CHANGING PERSPECTIVES ON PRIORITIES

It is important to note that also here the different levels of figure 2-6 play a crucial role. At the bottom level - the physical representation of the world - the national and international environmental quality monitoring systems dominate. Information from this level influences - and is also influenced by - the actions and rules of the societal actors (partly captured by models). These rules are changing as a consequence of the developments at the level of cultural values (top of figure 2-6). It is at this level that the debate about how sustainable development should be defined is taking place. Here, different perceptions of the functions of the environment play a vital role. The global and regional reporting systems should be flexible enough to take these different levels and perspectives, and the changes therein, into account. Regional priorities are, among other factors, a function of the phase of economic and demographic development.

5.2 ENVIRONMENT SYSTEM MODELS

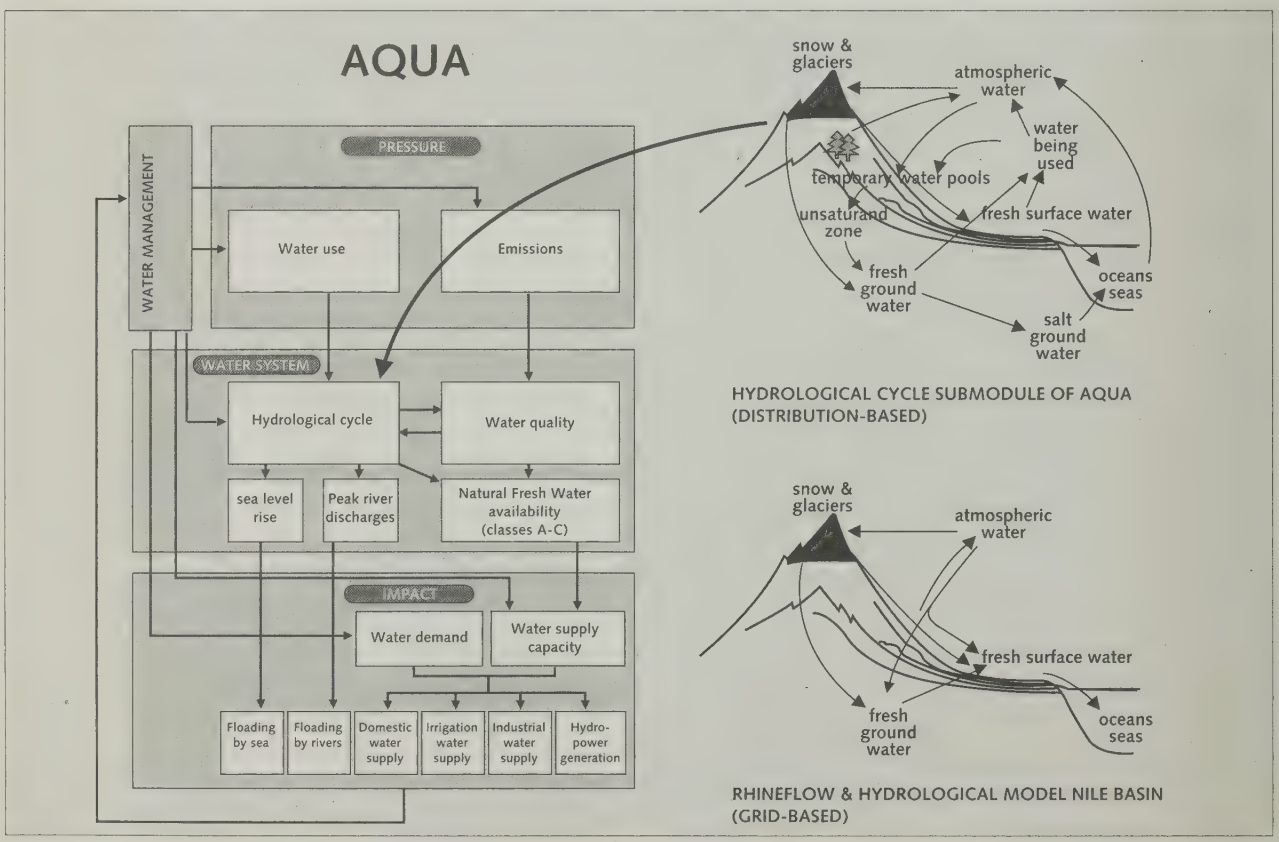
In part I we saw how, in order to develop outlooks and analyze scenarios, we could apply either separately or in combination, a suite of models to the different environmental issues. In this section we consider a number of models that have been or could be used for the objectives described in this report. Our selection focuses on those models operational or under development at RIVM, since it is with these that the authors are most familiar.

Figure 5-1 is a further elaboration of a model of the water system as part of the overall scheme in the TARGETS-model (figure 4-1). In this model the quantitative use and pollution of water represent the *pressure*, the hydrological cycle and water quality processes address the changing *state* of the water system, the *impacts* include those on public health, agriculture, industry and energy supply, and the water management module simulates the societal *response*. All elements are characterized by indicators or indices. As an example, a "water satisfaction index" is developed as an impact indicator that describes the percentage of the population with access to sufficient and reliable water supply. This example is further elaborated in a companion project (Heij, 1994).

Figure 5-2 shows an example of an integrated computer model of climate change and land use (IMAGE; Alcamo et al., 1994). As will be the case with many of the models that could be used for a global environmental reporting and assessment system, the framework proposed in this report is not immediately recognizable in the box diagram. But in fact, one can easily imagine another representation of the same model that would capture the pressure-state-impact-response cycle in the conceptual framework more clearly: Decisions on energy and land use (*response*) influence regional energy systems and land use practices. These lead to emissions (*pressure*) that alter the *state* of the atmosphere, the oceans and the terrestrial biosphere. These changes subsequently lead to changing functions (*impacts*), like changed agricultural productivity, flooding by sea level rise or shifts in vegetation zones.

The scheme of figure 5-3 represents the RAINS model of acidification being used extensively in support of the negotiations on long-range transboundary air pollution in Europe (Hettelingh et al., 1992). Again, the *pressure* (emissions) - *state* (aluminum mobilized in soils, low ph-levels of lakes), - *impact* (degradation of vul-

Figure 5-1: AQUA - a model of the water system integrated across the causality chain and linked to models of other themes in TARGETS (Rotmans et al., 1994).



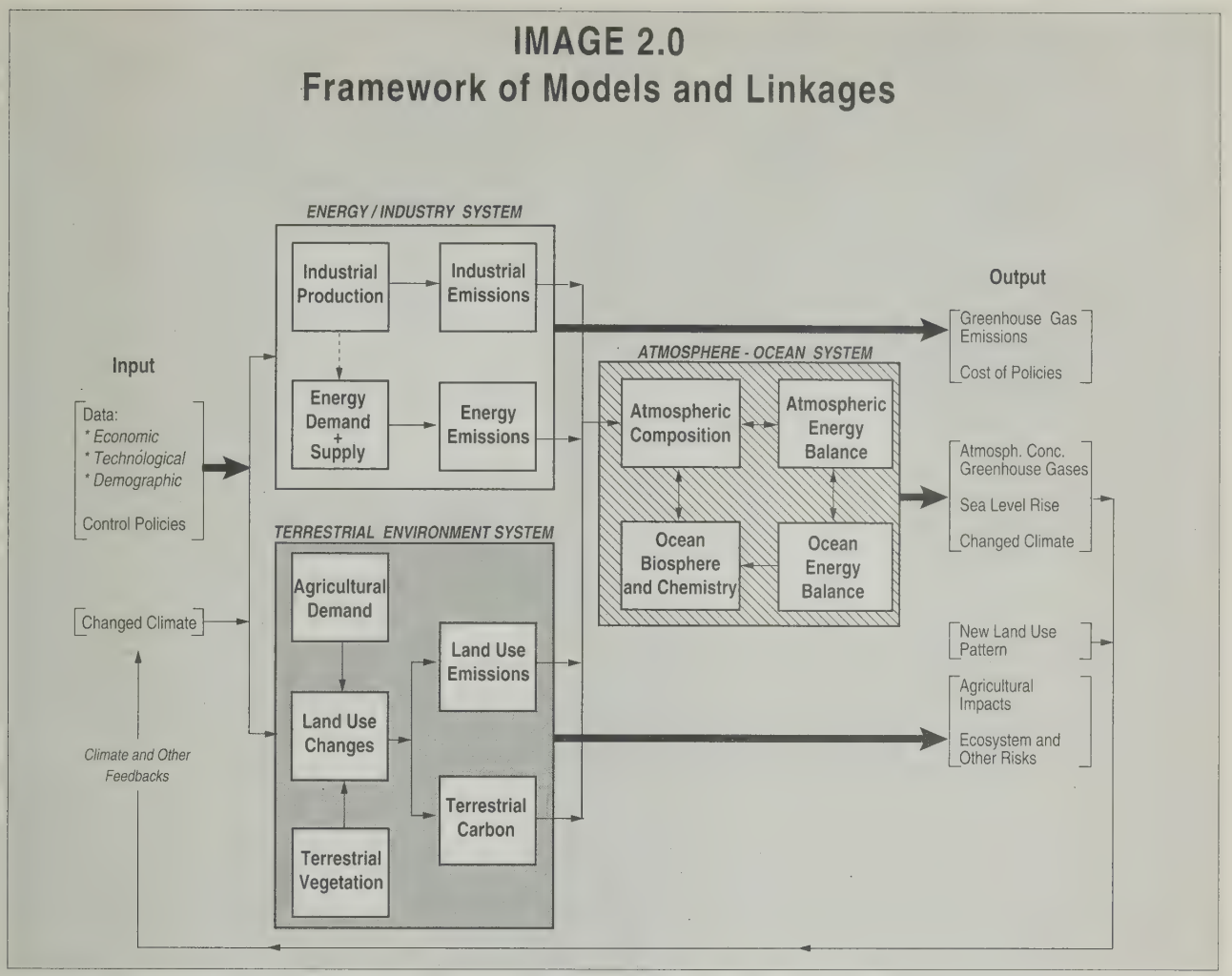


Figure 5-2: The Integrated Model to Assess the Greenhouse Effect (IMAGE)
Integration across the causality chain at the global level (Alcamo et al., 1994)

nerable ecosystems) - *response* (policy feedback) cycle can be recognized in the scheme. The RAINS model is also currently being adapted to support scientific assessment and policy development with respect to acid deposition and air pollution in Southeast Asia and China. These three examples share an integrated approach, which captures basic elements of the different subsystems including driving forces and natural and societal response.

The application of environmental models for regular reporting and assessment activities requires a coordinated effort. This specifically applies to the data used, the data format and the input assumptions. In appendix 2 an example is given of an integrated assessment of the state of the environment in Europe, using two of the above mentioned models (IMAGE and RAINS), with a consistent set of scenarios (Hettelingh et al., 1992). The study described in appendix 2 was supported by a set of separate models and, coordinated, amongst others, in terms of data and input assumptions. In contrast, the CARMEN model, now under development at RIVM, incorporates different models into one integrated framework, currently capturing acidification and eutrophication in Europe (De Haan et al., 1994).

Analysis of the combined impacts of different stress factors can also be supported by models. For example, the MOVE model forecasts what the occurrence probability of selected species is for different environmental scenarios (currently nutrients, acidity and moisture, to be complemented by climate change) (Latour et al., 1993). Figure 5-4a shows a simple representation of the model and figure 5-4b shows an application for the Netherlands, where different shades of grey represent different types of stress on selected plant species.

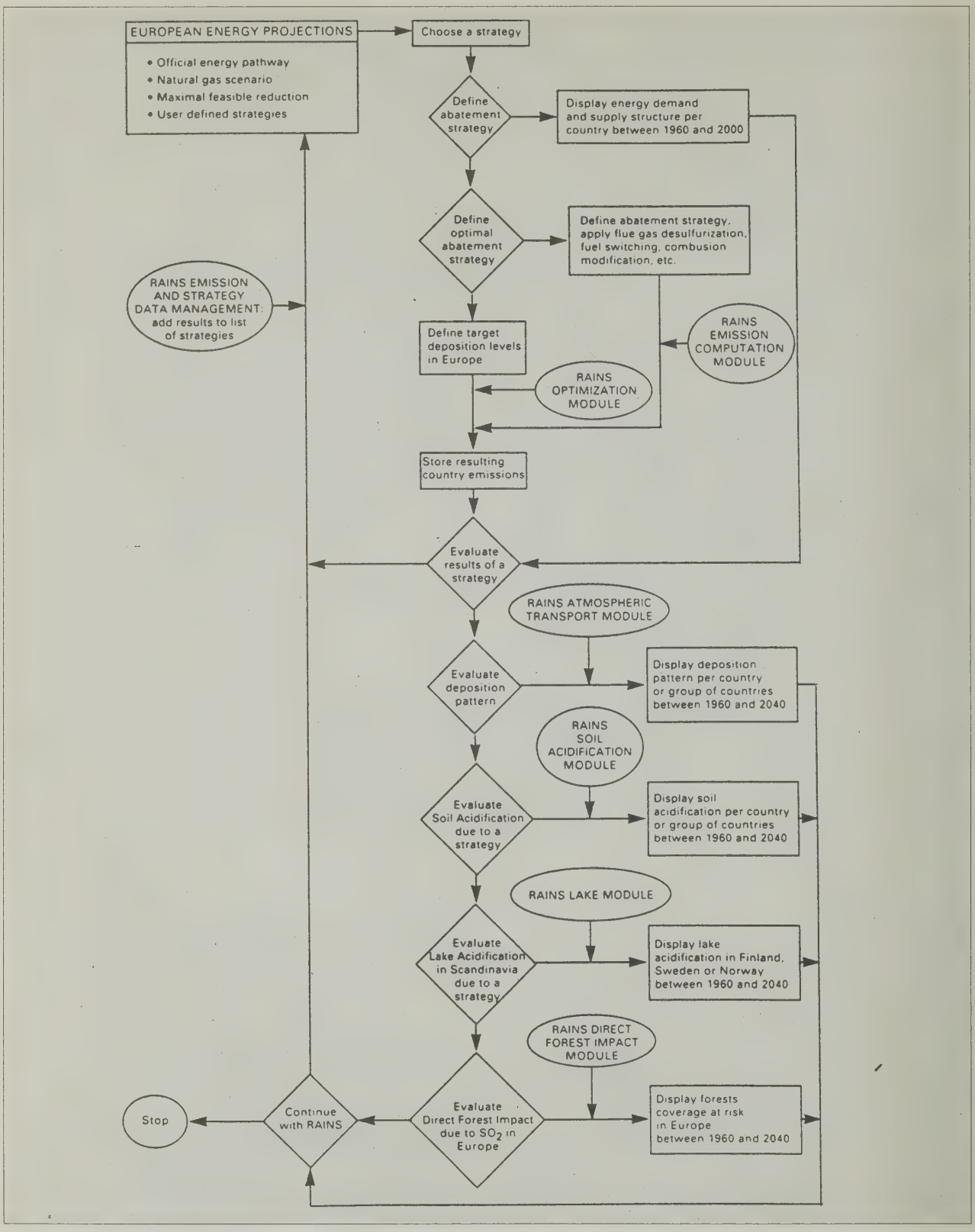
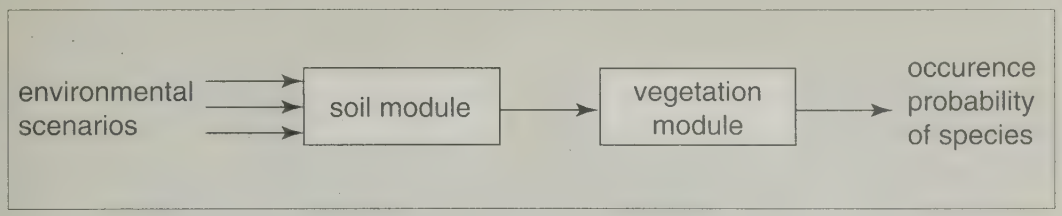


Figure 5-3: The RAINS-model of acidification
Integration across the causality chain at the regional level (Hettelingh, 1990)

a



b

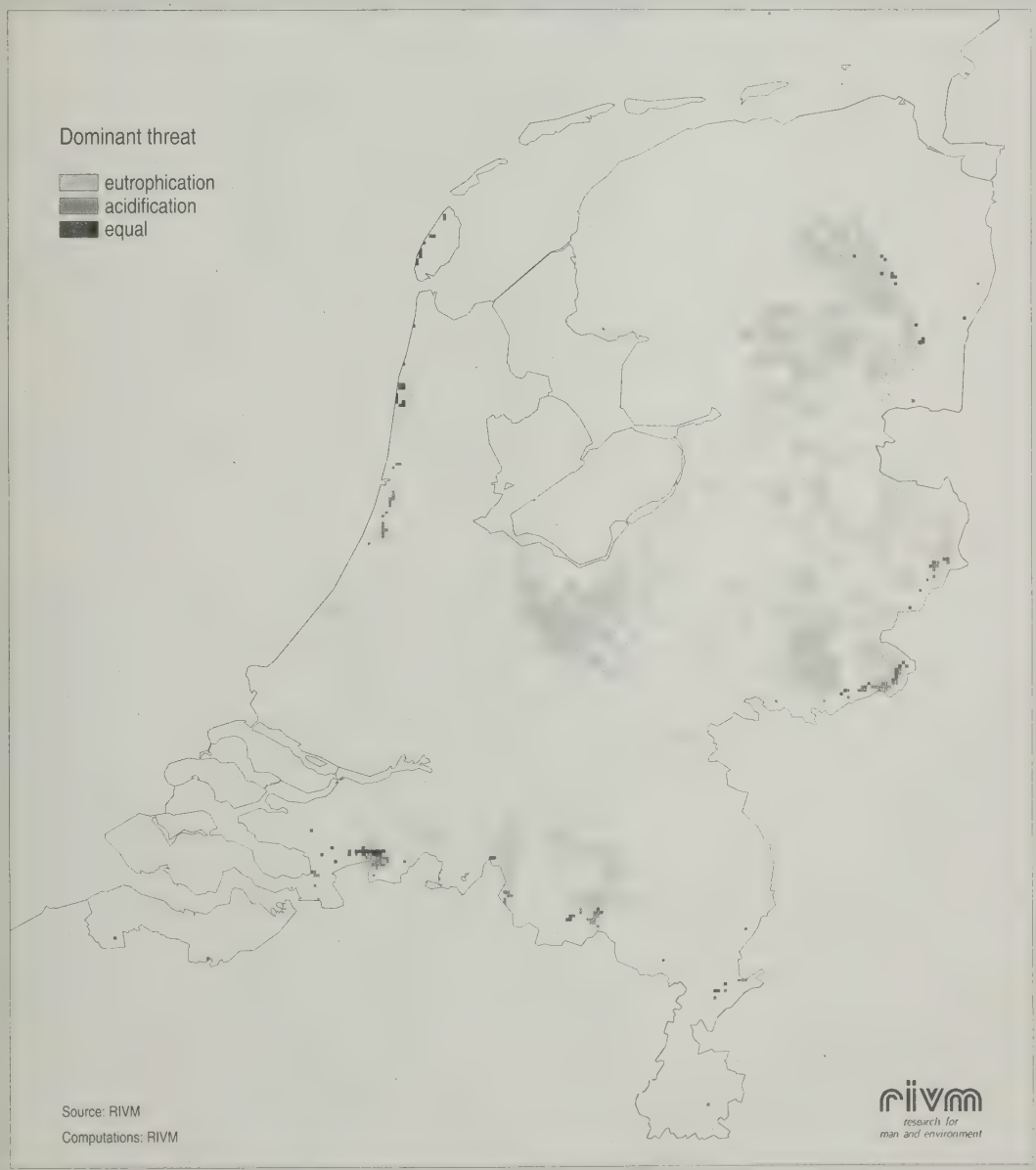


Figure 5-4: Multiple-stress modelling with the MOVE-model
a) simple model structure
b) application for two stress factors in the Netherlands

5.3 INDICATORS OF THE ENVIRONMENT SYSTEM

In chapter 3 it was argued that ideally a fully linked system of indicators should be the basis for integrated assessment and reporting.

Many sets of indicators have been listed, mostly at the national level, in industrialized countries (Bakkes et al., 1994). The most thoroughly debated set is that of the OECD (1993). Its thematic categories are reproduced in the entry column of table 5-1. This list of issues may not adequately reflect the special environmental problems of less-industrialized countries, like biological water quality. Coastal zones and marine ecosystems are also under-represented. Nevertheless, as was argued in section 3.1, this set may well be taken as a starting point for the development of thematic indicators for the environmental subsystem. (These are single issue indicators in the terminology of section 3.3.) In table 5-1, the other columns contain examples, by the authors of this report, for types of indicators proposed or developed for pressure, state, impacts and responses.

Table 5-1: Types of environmental indicators in the Pressure-State-Impacts-Response categories[1]

issues	pressure	state	impacts	response
climate change	emissions of green house gases	concentrations	climate change; sea level rise	energy intensity; env.measures
ozone depletion	halocarbon emissions; production	chlorine concentrations; ozone column	radiation change; excess skin cancer incidence	protocol sign.; CFC recovery; Fund contribution
eutrophication	nitrogen and phosphorous loads	concentrations N,P; BOD	degraded functions comp. standards	treatm. connect.; investments/costs
acidification	emissions of sulphur and nitrogen oxides and ammonia	deposition; concentrations	exceedence of critical loads; tree vitality	abatement costs sign. agreements
toxic contamination	emissions (persistent organic chemicals and heavy metals)	POC, heavy metal concentrations	humans health / ecosystems	recovery hazardous waste; investments/costs
urban env. quality	emissions VOCs, sulphur and nitrogen oxides	concentrations	human health; visibility	costs/investments measures; transp. & energy policies
biodiversity	land conversion; land fragmentation	species abundance comp.to virgin area	threatened species; extinction	protected areas
waste	waste generation per sector or emissions, leaching and land use by treatment and disposal	soil/groundwater quality	loss functions soil/ groundwater	collection rate; recycling investments/cost
water resources	demand/use intensity resid./ind./agric.	demand/supply ratio; quality	human health	investments/cost; water pricing; resource management
forest resources	use intensity forest disturbance	area degr.forest; use/sustain.growth ratio	loss functionality	protected area forest sustain.logging
fish resources	fish catches	stocks, age distribution ratio	overfished areas	catch regulation
soil degradation	land use changes	top soil loss	function loss	rehabilitation/ protection
oceans/coastal zones	emissions; oil spills; depositions	water quality	disturbance coral reefs, nature areas, impact (shell-)fish	coastal zone management; ocean protection
environmental index	pressure index	state index	impact index	response index

NB:this matrix is an elaboration of the environment part of the Sustainability Matrix (table 3-1)

[1]Themes from OECD (1993); oceans and coastal zones added; examples of indicator types and index row added by the authors.

5.4 TOWARDS REFERENCE VALUES

SUITABILITY OF EXISTING REFERENCE VALUES

In section 3.4 criteria have been formulated for the selection or development of reference values to accompany the indicators. Weterings and Smeets (1994) have compared a sample of existing reference values with these criteria, including the requirement of compatibility with the PSIR approach. They conclude that reference values exist or have been proposed for many environmental themes at the national and sometimes international level. Mostly, these values apply to environmental pressure, notably as emissions targets.

None of the sampled existing reference values meets the criterion that reference values for various environmental issues should ideally be based on an integrative and comprehensive notion of the environmental system. One should bear in mind that formulating separate reference levels for separate environmental issues implies neglecting the interrelations between issues. Since the environmental system is a dynamic system characterized by interdependencies between the subsystems and processes it consists of, neglecting these interrelations may well result in shifting rather than reducing environmental problems. Although some steps towards truly integrated reference values have been taken (Opschoor and Van der Ploeg, 1990; Rees, 1992; Annema et al., 1993; Rotmans et al., 1994), the reference values established - as well as the associated indicators - still remain mainly issue-oriented (see also Box 5-1).

PRAGMATIC POSSIBILITIES

No ready, coherent set of reference values exists. However, it is important to realize that there is an important element of iteration in the development of reference values in policy-oriented reporting. If it is acknowledged that reference values based on an integrative notion of the environment is what is eventually needed, then reference values could be 'borrowed' from other contexts in order to prime the reporting and assessment process in a pragmatic way. The text following table 3-1 in section 3.4 gives a broad categorization of possibilities. Obviously, such a pragmatic start would mean that first assessments would use an inconsistent and unconnected set of reference values based on quite different considerations. However, we do believe that even this, when applied throughout the assessment, in addition to the conceptual framework and the model-based linkages, would add considerably to its significance.

Some examples of reference values

Figure 5-5 illustrates an example of the exceedance of critical loads of acidification in Europe calculated by the RAINS-model (figure 5-4). In this RIVM study (Hettelingh , et al, 1992) we can clearly see how deposition levels beyond the critical loads are damaging to ecosystems across Europe.

Figure 5-6 illustrates the use of historical population levels for different indicator species as reference values in a so-called AMOE-BA-representation. (Example from RIVM, 1992; see Ten Brink et

Box 5-1: Determining the "Environmental Space" as a basis for reference values

Environmental space (Opschoor, 1987, 1989; Opschoor and Van der Ploeg, 1990; Weterings and Opschoor, 1992, 1994) is a notion that stems from a family of concepts such as: carrying capacity, ecocapacity and ecoscope. These concepts all express the idea that at any given point in time there are limits to the amount of environmental pressure the earth's ecosystems can take without irreversible damage to the systems or the life support processes that they sustain. The notion of environmental space focuses on the environmental functions provided by the biosphere to human society, necessary to sustain economic activities. It covers:

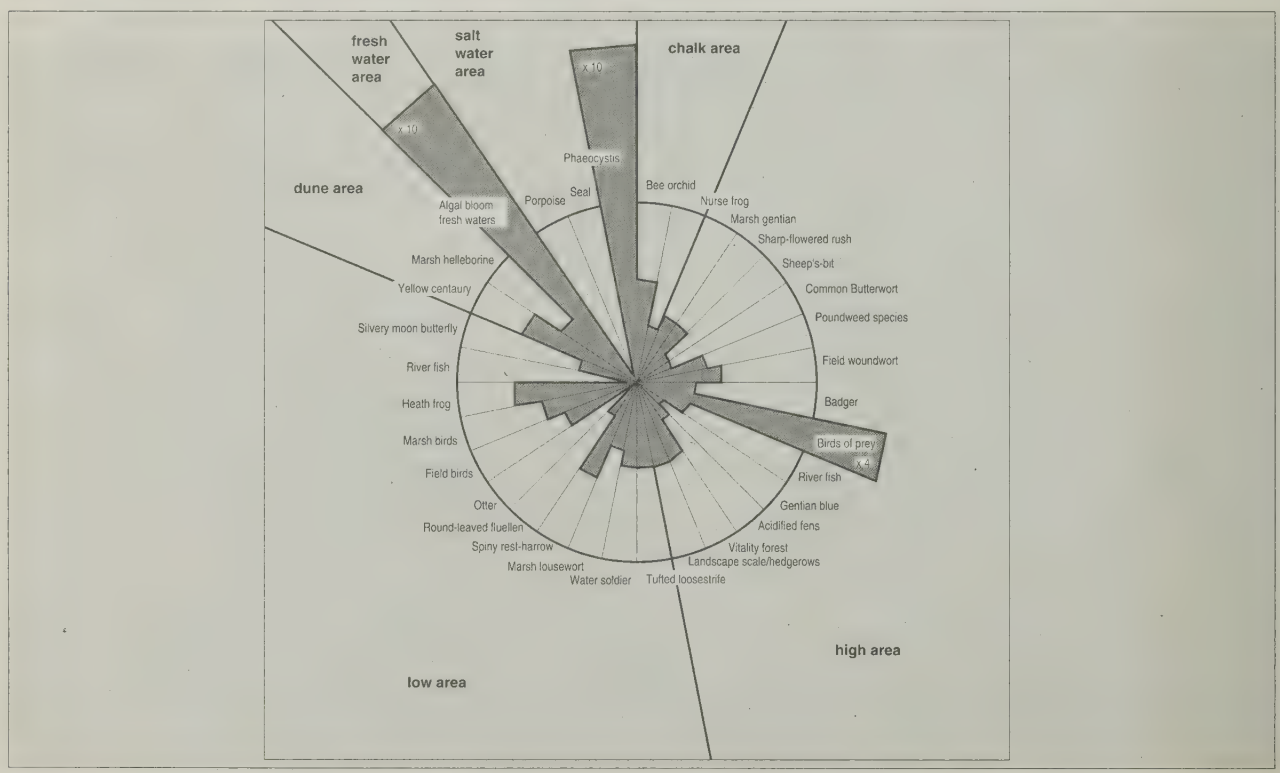
-stocks: the natural renewable and non-renewable resources available to human society, including the capacities to regenerate these resources;
-sinks: the finite capacities to absorb pollution and wastes and to buffer encroachment.

At the metaphoric level, the notion of environmental space seems clear. The initial suggestion it prompts may be to search for the critical levels of environmental pressure beyond which actual environmental systems might become damaged irreversibly and to regard these levels as being the operational boundaries of the environmental space. In practice, however, it soon appears that there is a series of reasons why a purely scientific approach for identifying the boundaries of the environmental space is impossible. In order to arrive at an operational set of boundary conditions, choices of a non- or pre-scientific nature have to be made. Some of these choices have to do with the limited capacity to predict impacts, other choices have to do with the definition of sustainability and with the basic values on the rights of access to (and use of) environmental resources of present and future generations.

One important feature of (the notion of) environmental space is that its magnitude is considered to be dependent on a range of interdependent and time-dependant variables both in the natural and in the societal domain. Consequently, the (notion of) environmental space is not static, nor does it 'freeze' its underlying variables at unique levels (Opschoor and Van der Ploeg, 1990). This also implies that there may be several ways of realizing or maintaining a given volume of environmental space, with improvement in terms of some conditions or variables compensating deteriorations elsewhere or in terms of other variables. In other words: there can be trade-offs. Trade-offs between environmental issues, as well as trade-offs between specific regional parts of the (global) environmental space.

Figure 5-5: Exceedances of critical loads for acidification in Europe in 1990 (Hettelingh et al., 1992)

Figure 5-6: AMOEBA:an environmental quality indicator for Dutch ecosystems; The reference value (perimeter) is the historical situation based on data of the 1900-1950 period; the situation shown is 1990. (RIVM,1992)



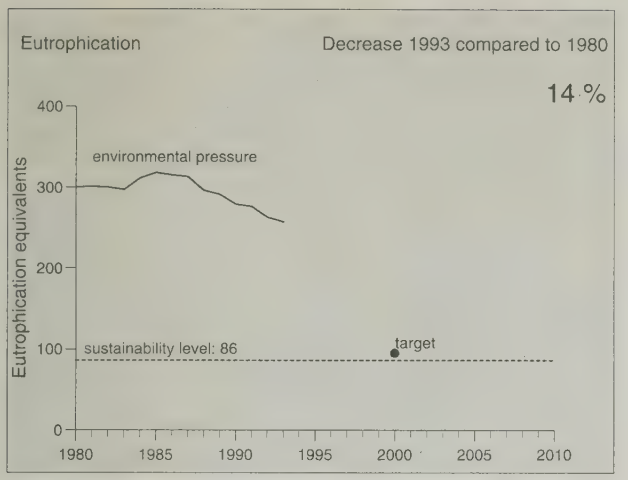


Figure 5-7: Eutrophication in the Netherlands (RIVM, 1993): Example of a policy performance indicator; reference value is derived from policy objective

al. 1991 for methodology.) If the hatched circle segments go outside the reference circle, the species population has increased. In addition, the desired population levels of the indicator species may be shown in the AMOEBA, acknowledging the fact that the desired situation may be different from the historical reference and that for some of the species an increase may not be the desired development.

Figure 5-7 illustrates the application of environmental policy performance indicators in the Netherlands for the problem of eutrophication. Eutrophication equivalents are calculated by a weighted addition of nitrogen and phosphorus loads. The reference value shown is the official policy objective.

These are examples of purpose-designed indicators with associated reference values. They represent indicators for one environmental theme and one element of the causality chain. As such, they show neither interactions with other elements of the causality chain, nor time delays.

CHAPTER 6

THE HUMAN SYSTEM

We saw in part I how the human system can be split into an "economy subsystem" and a "social subsystem" (figure 2-1). In section 6.1 we discuss some of the many perspectives on how the economy system works or ought to work. No attempt has been made to elaborate on any particular approach. In view of the focus of this report, we have tried to maintain an environmental view on economic modelling. Although economics is somewhat outside the scope of the report, it has strong linkages to the environment.
Section 6.2 deals with the social subsystem, in this case limited to a population subsystem. It focuses on a structured approach to two interrelated components of the population subsystem: public health and demographics. Future elaboration and extensions to the population subsystem should also capture elements of the social subsystem other than demography and health, such as social, institutional and cultural issues.

6.1 THE ECONOMIC SUBSYSTEM

INTRODUCTION

One of the key elements in the environmental management cycle is the degree to which economic forces affecting environmental changes can be influenced. Basic data and models for the economic subsystem are developed by such institutions as the World Bank and by regional or national research and policy institutes. These data and tools can be used in the proposed framework to analyze potential future developments, the dynamic interactions between the different subsystems and the options available to mitigate environmental degradation.

In this chapter we first briefly describe the connection between economic development and the use and availability of natural resources. Since our focus is on natural resources, the economic system (e.g. consumption and services, government, capital and labour markets) is only dealt with in so far as it generates the demand and the means for resource exploitation. Second, we present a brief overview of interpretative models. Finally, we discuss indicators of the functioning of the economic system in relation to resource use. The ideas and proposals are derived from RIVM's integrated modelling frameworks (Rotmans et al., 1994; de Vries et al., 1993).

THE ISSUE: ECONOMIC DEVELOPMENT AND NATURAL RESOURCES

The increasing pressure on the regional and global environment is caused not only by the growing population, but also by the ever larger throughput of materials associated with the life-styles of more affluent regions. These larger throughputs are directly associated with increasing human welfare, in the form of dwellings, cars, consumer electronics, roads, schools, hospitals etc. It has also become evident that they cause various undesirable side-effects among which is environmental degradation. Such externalities, as they are called in the economic literature, tend to offset part of the gains in welfare, although both welfare and the perceived loss of welfare through environmental degradation are difficult or even impossible to quantify in unambiguous and noncontroversial terms.

Where parts of the population are marginalized by prevailing social and economic allocations and distribution mechanisms, they may - on perfectly 'rational' grounds - resort to forms of resource exploitation which are unsustainable. Thus, poverty and destitution, it can be argued, lead inexorably to environmental degradation. Thus, it is unavoidable that equity aspects will need to be included in an integrated and dynamic global environmental reporting system.

Trend towards increasing resource productivity

The productivity of resource use has significantly increased over the last decades and centuries, partly in response to rising prices and partly in response to strategic and environmental considerations, but largely due to technological changes. In most nations, over the last 15 years, the amount of energy and minerals required per unit of production has been declining continuously. An exception has been in the use of electricity. Its share in total final energy demand has been rising. This is due to its high exergetic quality and versatility[1]. Another exception are those regions that are in the first stage of industrialization and therefore have experienced a rapid expansion of resource-intensive industrial activity, to some extent as part of a larger restructuring of global industry.

[1] The exergy content is a measure of the ability of energy to deliver power. For low-temperature heat it is about 0.06; for electricity it is 1.0.

To reduce the - anticipated growth of - pressure on the environment, such an increase in resource productivity will have to continue over the next decades. This will result from the many target-oriented research, development and demonstration projects, but it will also result from a variety of other technological changes. As yet, it is unclear whether such changes - e.g. in information technology - will interact with life-style developments in such a way that the net outcome will be a higher or a lower resource productivity. Also, the implications for social aspects of development, such as employment, are unclear.

Trend towards decreasing resource quality

Economic activities can be considered as the upgrading of natural resources to generate user value, to be discarded in the environment in a more or less degraded form at a later stage. From this point of view, the economy is in-between natural (re-)sources and sinks (Meadows et al. 1992). As in all ecosystems, upgrading requires a continuous input of exergy. One source of raw materials for upgrading are those ecosystems which allow the extraction of plant fibres or the utilization of animals for food, energy or materials purposes (crops, fish and meat; biofuels, animal traction; wood, leather). Another part of the raw materials to be upgraded are minerals which constitute an endowment of widely varying quality and location. There is ample evidence that over the last century the quality of such resource stocks has been declining, showing up in decreasing ore grades, diminishing fish size and the like. Due to a variety of productivity-increasing developments and supply-demand dynamics, it is still a controversial issue whether there is a long-term rise in costs of exploitation for many resource stocks.

The other key resources are the stocks of carbon-based fossil fuels. These too are faced with depletion, showing up in greater extraction depths, longer distances to the markets and the like. Here too the impact of depletion has been masked by productivity increases in exploitation, transport and upgrading. Exploitation and use of fossil fuels have over the last two decades been confronted with increasing environmental abatement costs and additional health and safety costs.

Models can play an important role in furthering the understanding of issues such as increasing resource productivity and decreasing quality and quantity of resource stocks in relation to social, cultural and environmental developments. These are discussed below.

BRIEF OVERVIEW OF ECONOMIC MODELS

Categories of economic models

We can distinguish four approaches to modelling economic developments on a long-term global scale which have been designed from an industrial-world perspective (Boero et al, 1991). Each has its merits and limitations.

Resource allocation models, which concentrate on the efficient allocation of resources using static choice-theoretical methods, are the most widely used. These can be split up into *general equilibrium models* such as Whalley and Wigle (1991) and the OECD-GREEN model (Burniaux et al, 1991a,b) and *partial equilibrium models* (Edmonds and Reilly, 1983a,b; Manne and Richels, 1989, 1990). Although general equilibrium models stress the interconnectedness of the economy and explore the effects of changes in relative prices on all sectors, their main limitations are data demands and their ignorance of non-optimizing behaviour. Partial equilibrium models can be used for a broader set of analyses, and can analyze sector effects on a more detailed level, although the interconnections between sectors are rather scarce.

The second category of economic models is **macro economic models** which have better articulated dynamics and are able to give more robust economic predictions on a short time horizon. Their main limitation is that they are not robust over medium and long term horizons. An example of this approach can be found in Jorgenson and Wilcoxen (1990).

The third category, **optimal growth models**, is a particular species of macro models which assume perfect foresight in order to derive the optimal balance between consumption and investment. An example of this approach within environmental modelling is the DICE model of Nordhaus (1992).

Finally, the fourth class of models are models based on **system dynamics.** They describe the economic system as a non-linear dynamic system including feedbacks and delays and limited foresight. This is the approach which is used in the TARGETS/GESPE framework (de Vries, et al., 1993) and forms the basis of the following illustrative discussion that aims at describing how a systematic analysis of the economy system could be structured in the context of integrated environment assessment, including the proposed PSIR framework.

Previously developed System Dynamics models have been used as a starting point for a number of TARGETS/GESPE submodels (Meadows et al. 1973, Sternman, 1981). Because the dynamics of the economic and resource systems are to such a large extent governed by human decisions and behavioral rules, they are loaded with value judgments. The information on which such decisions and rules are based, e.g. the size and quality of a resource stock, is often clouded with uncertainty. One of the conse-

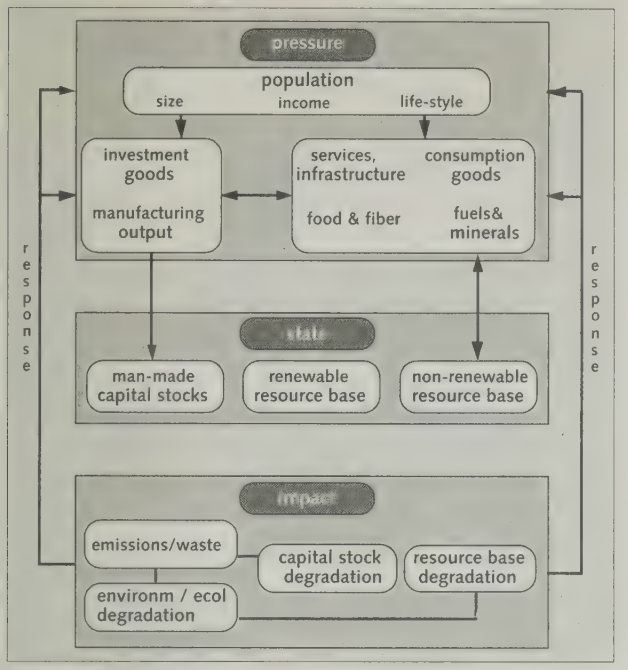


Figure 6-1: Representation of the economic subsystem in the PSIR framework

quences is that modelling such systems at the aggregated world level has quite limited relevance in most areas. Another consequence is that there are no unanimously accepted models to describe these systems.[2]

A representation of the economic-resource system in TARGETS/GESPE is given in figure 6-1. It is an attempt to capture the workings of the economic system by the pressure-state-response cycle, in spite of the inherent difficulties. With population and its various characteristics as the main driving force, economic output is partly used for consumption and partly used to maintain and expand industrial production. *Pressure* can be indicated by investments. No generally accepted rules can be established for the allocation mechanisms, although cultural, political and strategic considerations play an important and often unique role. Within the Targets/GESPE-framework the allocation decisions are made part of interactive simulation c.q. policy exercise. The main *state* variables within this submodel are the man-made capital stocks and the natural capital stocks (renewable and non-renewable resources). To run the economic system, these resources have to be exploited - showing up as flows of food, fibre, fuels and minerals. The effects and *impacts* of sustaining these resource flows can be represented by changes in productivity (e.g. GDP-loss), on welfare or on the quality and productivity of the man-made and natural capital stocks on which the system runs. Finally, autonomous or policy driven changes in investments patterns such as economic instruments, can be regarded as *responses.*

While international academic discourse about the different schools of thought has been lively for decades, such debate remains largely absent in policy circles. In fact, the recent initiative of the Intergovernmental Panel on Climate Change (IPCC) on the economic implications of climate change strategies (one of the "crosscutting issues" of the newly established Working Group III) is one of the first world-wide policy-oriented assessments. It covers the advantages and disadvantages, possibilities and limitations, and associated specific roles of different types of economic models in support of major policy decisions on the world's economic system.

The role economic models can play in integrated environmental assessment reporting is clearly an important question. Ideally, a fully integrated assessment across the environmental management cycle and across different components of the human and environmental systems would fully acknowledge the role of economic factors. However, the wide variety of views on the role of economics and the choice of methods continue to impede consensus on such an approach. Consequently, for integrated environmental assessment reporting, the emphasis may lie initially on the assessment and forecasting of environmental changes, taking available scenarios of socio-economic driving forces as input. Scenarios by international organizations, such as the World Bank or IPCC could be taken as a starting-point. However, regional expectations and ambitions should eventually be better reflected. At the same time, a debate could be started on how to deepen and broaden the integration of economic factors in integrated environmental assessment reporting. As mentioned above, such a discussion has already been started in the area of climate change, in the preparation of the second assessment report of the third Working Group of IPCC on crosscutting issues, and in the debate about ways of evaluating the effectiveness of policies, as required by the Framework Convention on Climate Change. The costs and economic implications of different response strategies can be estimated, using a variety of methodologies. In integrated environmental assessment reporting this variety of views on costs of environmental strategies may be reflected.

ECONOMIC AND RESOURCE INDICATORS

Over the past decades, a plethora of economic indicators based on

[2] In the TARGETS/GESPE-project, RIVM is trying to cope with this by using explicit actor descriptions based on observations and insights within the region. These projects also aim to embed the simulation models in a learning environment that supports communication about how people are perceiving issues and thus help generate alternative strategies ("policy exercises").(Morecroft and Sterman, 1992).

extensive data collections has been proposed. The best known of these are indicators like GDP growth c.q. GDP per capita and trade deficit, showing economic performance. Vigorous debates are going on about the adequacy of these indicators. Each actor tends to favour a rather limited set of indicators, if only because people can handle only limited amounts of information - and only with limited rationality (see e.g. Morecroft and Sternman, 1992). It is clear that due to its definition GDP growth is a inadequate measure of welfare from an environmental perspective - much of the growth in money flows may actually reflect a decline in quality of life instead of an improvement. Hence the proposals to design a "green" GDP, an Index for Sustainable Income and the like (see e.g. Cobb and Daly, 1990). Similarly, corrections for purchasing power and ways of incorporating the large informal economy of less developed countries express the unease with which the conventional indicators are being used by many people.

Obviously, the choice of indicators is dependent on one's particular paradigm. Recently, progress has been made in compiling indicator sets that capture the important aspects of the economy from an environmental point of view and follow the distinction between driving forces, state, possible impacts, and responses. Proposals can be found in work at the World bank (World Bank, 1995; see table 2-1 in this report) and DPSCD (1995). These proposals clearly reflect an early stage of development and are yet incomplete. A more comprehensive menu of possible indicator types for the economic subsystem was given in table 5-1 (See section 5.3).

6.2. THE POPULATION SUBSYSTEM

INTRODUCTION

Although the viewpoint of this report is based on the environment subsystem, in the integrated analysis the interplay with population change and socio-economic development is of key importance. This part of chapter 6 elaborates the ideas about the social subsystem put forward in part I. It focuses on population growth and population health status as a function of social, economic and environmental change. After a brief outline of complexities of the main issues, it describes 1) an interpretative model for analyzing information and 2) the development of human system indicators to structure this information in support of the development and evaluation of an integrated environment and health policy. This description is based on the development of a global health model as part of the TARGETS integrated world modelling framework (Rotmans, 1994; Niessen and Rotmans, 1993).

The data necessary for composing the different indicators and the methodological tools for the prognosis and forecasting functions could originate primarily from the international organizations active in the areas of health and nutrition as well as education and social development, such as WHO, UNICEF, FAO, UNESCO and UNDP.

THE ISSUE: PUBLIC HEALTH, THE ENVIRONMENT AND DEVELOPMENT

Socio-economic development and (accompanying) lifestyles largely determine health levels. Important sectors contributing to improving standards of health include food and drinking water supply, education, communications and income. Nutritional status especially has been a most important factor influencing both the birth outcomes and the survival of water- and airborne childhood infections (WHO, 1990, 1991, 1992; World Bank, 1993; UNICEF, 1991). Human health is an important indicator of social development. Beyond a certain level, however, there are diminishing health returns with an increasing throughput from social and health services. A number of countries have succeeded nonetheless in reaching high levels of health despite a low income per capita (see for an overview: Murray and Chen, 1993; Ness et al., 1993).

Large differences between populations and within populations remain in both premature mortality and in amendable morbidity. The advantages and disadvantage of the various multi-sectorial and target-oriented strategies to reduce these differences need to be assessed, given the potential health benefits of environmental improvements (WHO, 1981; UNICEF, 1991). In recent years (World Bank, 1993) more attention has been paid to the cost-effectiveness of health and environmental interventions. Methodologies to assess health gain at the population level still are poorly developed.

Health changes stemming from changing environmental conditions were a side effect of economic development. Of these the most acute have been the direct health damaging effects of local environmental problems, especially air and water pollution. On the longer term, larger-scale environmental problems like soil degradation, climate change in relation to the prevalence of vector-borne diseases, as well as depletion of the ozone layer may potentially cause health damage (Leaf, 1989; Doll, 1992). There is also a definite need in this area for the development of new methodologies to account for the complexities involved in the assessment of these effects (McMichael, 1993), for both the direct and indirect health impact of global change.

AN EXAMPLE OF A POPULATION HEALTH MODELLING APPROACH

The complexity of the population-environment relationship demands a broad integrated framework. Interpretive mathematical population models could contribute to more insight in both the vertical (= cause-effect) and horizontal (= exposure and effects

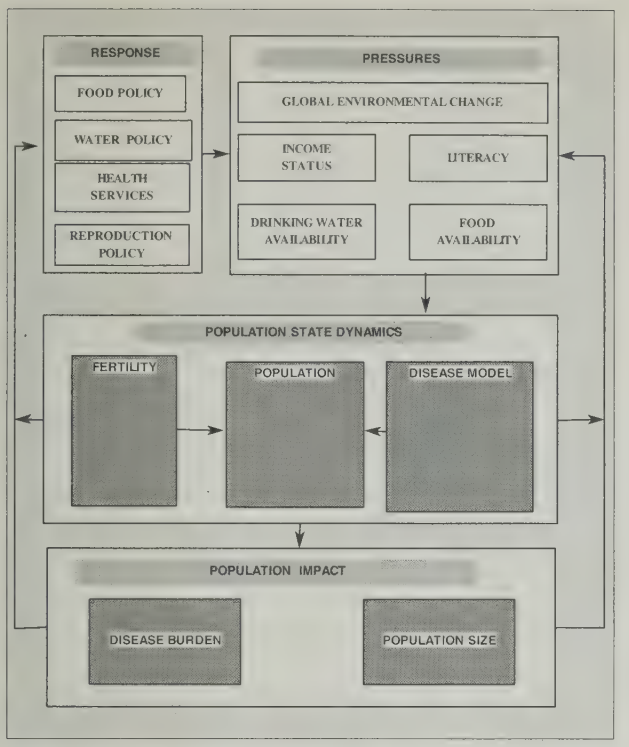


Figure 6-2: The integrated population health simulation model in TARGETS

of competition of diseases and substitution of one disease by another) dynamics taking place within the population. Once validated against historical time series and made internally consistent the modelled dynamics can serve early warning purposes by indicating potential environment-related health problems before they are actually revealed.

The proposed modelling methodology builds upon previously developed models aiming at an integrated health assessment (Niessen and Rotmans, 1993). The overall structure is based on existing international theory (Murray and Chen, 1993 for an overview). It incorporates a dynamic approach to the building up within populations of health assets, such as food supply, health services and health knowledge. It also includes the effectiveness of (public) health services and the delays of exposure and health service effects (De Vries et al., 1993). The disease modelling is based on Anderson and May's model (1993) for infectious disease and on Niessen's (1993) and Bonneux's (1994) for chronic diseases. This kind of disease modelling has so far been primarily applied to national level health problems. This is the first time that these models are being used on a global and regional scale, although some related simplified modelling has been used for static global calculations (World Bank, 1993). Calibration and validation of the model will be based on global and regional population time series as well as time series of total and disease-specific mortality rates (WHO, 1994 and World Bank, 1993).

Figure 6-2 shows a diagram of the components of an interpretative model of the health subsystem as well as illustrating how population and health issues are structured. The integrated modelling approach aggregates the data on the forces driving health as well as those regarding health impacts (i.e. morbidity and mortality levels) also for data on population and health related issues,. At the same time it identifies the gaps in the national and international information systems. The interpretative mathematical model identifies the specific contributions of social, economic and environmental changes to the loss of potential (healthy) life years.

Like the environment, the population health area can also be described according to the pressure (health determinants) - state (population and fertility dynamics) - impacts (morbidity and mortality) - response (public health and socio-economic policies) framework (see figure 4-1). Inputs from other sectors (water, food production, economy and global environmental change) act on the population.

In the TARGETS model, the population projections generated by the population module form the major feedback loop to the other modules; in this way the dynamics of the interplay between population, the environment and development can be described[4]. The integrated disease-specific approach chosen in this model accounts for the simultaneous occurrence of multiple health risks and diseases (Niessen and Rotmans, 1993). This corrects for the major shortcoming in the non-integrated, single-disease approaches used so far (eg. World Bank 1993). Changes in the occurrence of one health risk might affect the occurrence of various other health risks (diseases) at the same time, e.g. through food supply.

Furthermore, changes in one health risk might be nullified by the presence of high risks from other causes like the common childhood diseases in developing countries. This methodological approach is currently being developed further by RIVM in consultation with the Population, Health and Nutrition Department of the World Bank (Niessen, 1995 (in press)).

Pressure

The pressure part consists of a socio-economic force determining

[4] Indirectly, potential global climate change might influence health levels by affecting harvests (Parry, 1994). In some areas the result may be increased desertification and deterioration in crop quality and in other areas there may be a beneficial increase in food production. The global balance of these effects and their consequences on food availability is still unclear.

water and food availability, income distribution and literacy level as well as health services levels. Global environmental change is modelled through potential changes in local food availability and nutritional status of the population. Nutritional status distributions are calculated based on the standard FAO-methodology (FAO, 1992) which also takes the influence of income status into account. Environmental change also potentially changes disease incidence, like malaria, and survival, like cardiovascular survival (see for an overview McMichael et al. 1994). These broad health determinants are combined with more classical health risk factors (see table 6-1). The selection of health determinants and disease categories will depend on local and regional priorities and the degree of environmental degradation. The effects of health determinants are quantified using the population attributive risks presented in the epidemiological literature.

Table 6-1: Types of exposure including overlapping and interdependent categories

Examples of single exposure categories
1- Income status
2- Tobacco use
3- Malnutrition status
4- Malaria presence
5- No access to clean drinking water
Examples of multiple exposures
7- High income and using tobacco
8- Low income and no access to clean drinking water
9- Malaria parasite presence and no access to clean drinking water
10- Low income, malnourished and malaria parasite presence
11- Low income and no access to clean drinking water

State

The demographic component describes the state of the population in terms of human stocks and flows. It includes a fertility module, based on an internationally accepted fertility model (Bongaerts et al. 1984) including the proximate determinants of fertility levels computing total fertility rates. This is being developed further and validated by the Centre for Population Research of the Groningen State University to include the most important factors determining fertility transition. Fertility changes are computed with reference to the effects of the level of human development (as measured by the human development index) and the child mortality rates (Willikens et al., 1994). In the module these are determined by income expectation and female literacy level which change infant mortality rates, desired family size and contraceptive prevalence rate. These fertility rates are input to a standard demographic module, which calculates the stocks levels for each age and sex, and then calculates the specific mortality rates based on the added-up disease-specific mortality rates computed in the health impact module.

Impact

The health effects are computed in the health impact component, which distinguishes various disease states and disease-specific mortality rates. The health module includes those effects of determinants and diseases that are considered to contribute substantially to population health levels (World Bank, 1993; see table 6-2 for examples). Disease categories such as malaria have been selected that are relevant to environmental degradation - especially decreasing food production, air and water pollution, and extreme climate changes. All other health risks and diseases are included in one general "residual morbidity" and "residual mortality" category. The disease module accounts for the disease-specific recovery rates, case-fatality ratios and disease recurrence. All impact figures combined determine the overall population levels of health, disease and death, which can be expressed in life expectancy and in the disability-adjusted life years lost (World Bank, 1993, see next section). Because the main determining factors of health levels have been included, the above population health measures can be divided up in broad and more specific determinants of health i.e. environmental and socio-economic factors, including lifestyle.

Response

Possible societal responses related to social and health policy (see figure 6-2) can be included in the response to the health impact levels or added as a separate response module for the model user. Preventive interventions in the various health sectors modify the forces in the pressures component. Other policies may address other elements of the PSIR cycle, e.g. how curative measures can directly affect health impacts.

INDICATORS OF PUBLIC HEALTH

In the TARGETS project three levels of aggregation are distinguished in the population health area. In figure 6-3, the indicators that are derived from the population sub-modules are depicted as a index-tree. The actual choice of the aggregation level, weighting and selection of the indices to be used will, again, have to take place according to local and regional priorities. Above all, they will depend on the stage of socio-economic development. Population policies could be evaluated through the use of indices, taking the various policy areas, including distribution and access issues into account.

The regular model output figures are depicted at the least aggrega-

ted level. These are based on the various stocks and flows of the model. Routine pressure and impact statistics in relation to the health transition level of the population and the level and nature of the epidemiological transition are collected from routine data registries. Presented in time series, these are to be used for historical validation. At the second level, indices can be defined for the four individual PSIR-components as a whole. Most of these indices are already being used in international reporting. At the highest aggregated level an overall population health index can be defined comparable to the UNDP human development index (UNDP, 1993).

Pressure

Risk levels for the population level are expressed in terms of people exposed. Danger thresholds have been defined based on research results usually found in experimental settings. Using the relative risk associated with a particular exposure, one can calculate the population-attributive risk which indicates the proportion of disease incidence that is explained by the level of exposure. At the pressure level, an overall "health risk" index is proposed which adds up the risks related to all determinant categories while weighting for their contribution to the incidence of diseases. The use of a discount rate is possible to correct for the moment in time when disease incidence occurs. No weighting takes place for the age at which disease incidence occurs. Because of the delays involved, this pressure index will provide an early warning signal for potential future health changes.

State

Two state indices are proposed: one related to fertility and one related to population structure. The fertility index expresses the percentage of children born that have been planned: the "planned births ratio". This ratio depends on actual effective contraceptive use and desired family size. There are quite a number of related empirical data sources available from censuses, demographic surveys and family planning programmes. This fertility index demonstrates the potential for fertility change and, hence, the momentum of population growth.

The second proposed index is the dependence ratio. This describes the number of dependents within a population, i.e. those under 15 and those above 65 years of age, as a proportion of the whole population. As this index indicates, the position of the involved population within the demographic transition it will therefore describe the proximity of the population to a possible steady state.

Impacts

Health status assessment at the population level implies a quality-of-life measure. This is expressed in the health expectancy measure. Up until now, a population's health has been measured by its overall life expectancy, stressing the gains in mortality reduction and, hence, gain in absolute life years. Recently (World Bank, 1993), composite quality measures, including those life years spent with disease, have been made operational, making use of internationally available health statistics. Weighting the total years lived for the time spent with and without disease leads to a measure of disability-adjusted-life-years per 1000 persons (the *daly* measure). In calculating this measure the severity of the disease is weighted according to a disability scale that consists of six categories. In this way, time lived with a disability is made comparable with the time lost due to premature mortality. The value of time lived at different ages is captured using an exponential function reflecting the dependence of the young and the elderly on adults. A 3% discount rate is used in the calculation of total lost life years.

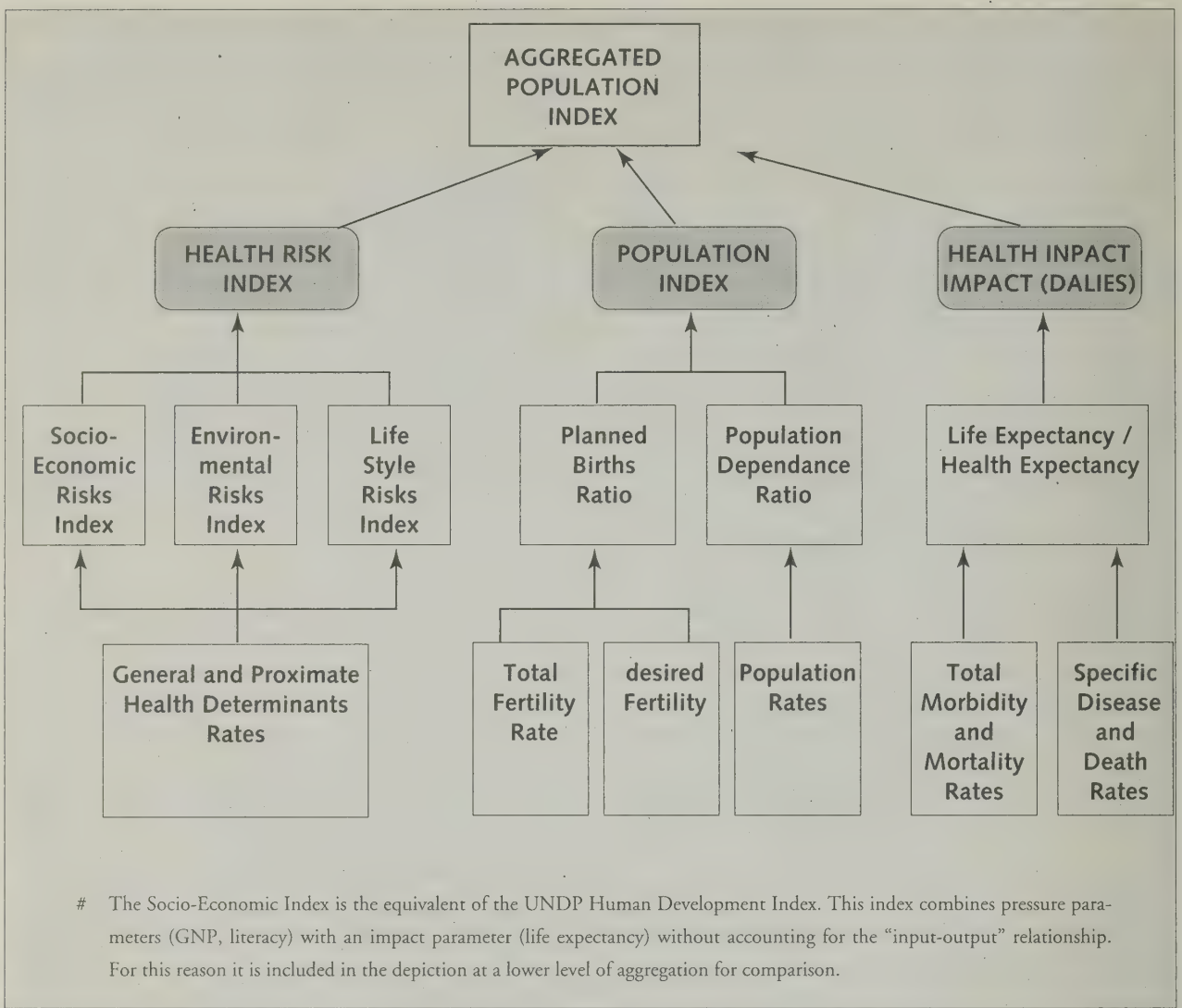
In most areas of the world, the empirical data are still insufficient to monitor trends in this index based on disability-adjusted-life-years. However, efforts are being made to do this through the central offices for population statistics. The available data on *dalies* are based, again, on modelling i.e. life-table extrapolations and a Delphi-like method (World Bank, 1993).

Response

Customary indicators for this component are the percentages of the available budgets that have been allocated for particular social or health policy areas. Other lower level indicators in relation to social and health regulations are also used (e.g. level of educational requirements). Budgets can be summarized at an aggregated level.

Table 6-2: Types of disease categories including co-morbidity categories and dependencies

Examples of single diseases
1. Gastro-enteritis
2. Acute respiratory infections and chronic obstructive pulmonary disease (COPD)
3. Malaria
4. Lung cancer
5. Cardio-vascular diseases
Examples of co-existing diseases
6. Cardio-vascular diseases and lung cancer
7. Cardio-vascular diseases and COPD
8. COPD and lung cancer



The Socio-Economic Index is the equivalent of the UNDP Human Development Index. This index combines pressure parameters (GNP, literacy) with an impact parameter (life expectancy) without accounting for the "input-output" relationship. For this reason it is included in the depiction at a lower level of aggregation for comparison.

Figure 6-3: Health indices in an integrated framework

One aggregated population health index

None of the important indices outlined above describes the population health situation as a whole. The advantage of choosing a still higher level of aggregation, combining the above indices, is that we would have a single health index for the population as a whole, accounting for the health risk, the demographic state and health status, inclusively. The above indices need to be weighted, scaled and aggregated. Weighting of health risk versus actual health loss will depend on the level of risk one is prepared to accept. Weighting fertility and population indices versus the pressure and impact indices will depend on the kind of population policy chosen. At the next stage, scaling and aggregation will lead to one overall index describing population health in time.

APPENDIX 1

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APPENDIX 2

THE ENVIRONMENT IN EUROPE: INTEGRATED ASSESSMENT MODELLING AT THE REGIONAL LEVEL

As an illustration of the integrative approach presented in this report, the results of integrated assessment modelling at the European level are summarized in this appendix. Scenarios were developed within the framework of the preparation of the European Community's 5th Action Programme on the Environment. Results were partly presented in the report "The Environment in Europe: a Global Perspective" (RIVM,1992). The example is elaborated here, because it is one of the few attempts to arrive at a model-based integrated assessment of a number of environmental problems at a multi-nation level. The assessment is partly integrated through common scenarios for driving forces and a comprehensive treatment of the causal chain.

INTRODUCTION

The study addresses a number of environmental problems in Western and Eastern Europe, that may result from socioeconomic developments at the global, continental and regional level. Through Integrated Assessment Modelling the (potential) global environmental problems related to various trends in energy use, CO_2-emissions and the use of CFC's are described, as well as continental environmental problems due to transboundary air pollution (tropospheric ozone, winter smog, radioactivity and acidification). In addition regional scale problems like soil and groundwater pollution (due to nutrients, pesticides and land fills), erosion, pollution of European rivers and seas and air pollution in cities are addressed. Using RIVM's air transportation models, the effects of emission scenarios on concentrations and depositions were calculated and compared with human health risk standards (WHO) and critical loads for ecosystems.

Although the study presents an integrated analysis of a broad range of environmental problems, this summary necessarily concentrates on two environmental problems: climate change and acidification.

ENVIRONMENTAL PRESSURES

Future implications of environmental policies are described for two contrasting policy scenarios:

* GLOBE I in which current trends in development and environmental policies continue, and which is consistent with the convential wisdom scenario of the EC, the Overall Economic Projections of UN-ECE and the business-as-usual scenarios of the IPCC;
* GLOBE II in which full implementation of best available technologies and policy options in both Western and Eastern Europe is assumed and which is consistent with the accelerated policy scenario of the IPCC.

Table A presents scenario data in GLOBE I and GLOBE II for Western Europe (WE) and Eastern Europe (EE).

The following trends in environmental pressures (emissions) are related to these socioeconomic trends:

Climate change:

Global trends in CO_2-emissions due to fossil fuel combustion for GLOBE I, GLOBE II are presented in figure A. In order to illustrate the effect of any European climate policy three additional scenario's have been considered in which the energy related emissions produced by Europe have been varied. European CO_2-emissions for GLOBE I and GLOBE II and one additional scenario (the implementation of EC Carbon tax) are presented in figure B.

Acidification:

In the GLOBE I scenario emissions of acidifying components decrease in 2010 with respect to 1990 by about 30% (SO_2) and 20% (NO_x); ammonia (NH_3, NH_x) emissions in GLOBE I are expected to increase by about 5% between 1990 and 2010.
In the GLOBE II scenario the extra reductions of SO_2 and NO_x emissions will result in overall decreases in 2010 with respect to 1990 by about 80% (SO_2) and 60% (NO_x); ammonia emissions are expected to decrease by about 40%.

ENVIRONMENTAL STATES AND IMPACTS

Prognoses of the changes in environmental state (atmospheric concentrations, depositions) and of the environmental impacts (temperature rise, ecosystem stress, critical loads) related to these trends in emissions have been obtained through computer models.

Climate change:

By means of RIVM's Integrated Model to Assess the Greenhouse Effect (IMAGE) the CO_2-equivalent concentrations and corre-

Tabel A: GLOBE I and GLOBE II scenarios for Western (WE) and Eastern (EE) Europe

	1990		GLOBE I 2010		GLOBE II 2010		
	WE	EE	WE	EE	WE	EE	
Population	353	352	367	406	367	406	mn (10^6)
GDP	2400	1185	3990	1780	3990	2290	bn (10^9) ECU
GDP/Head	6.7	3.3	10.8	4.4	10.8	5.6	1000 ECU/person
Total energy	57	65	72	102	57	70	EJ (10^{18} Joule)
Non fossil	11	5	16	12	17	15	EJ
Fossil energy	46	60	56	90	40	55	EJ
Foss.energy/GDP	20	50	14	50	10	25	PJ/mn ECU
Energy prices	15	15	28	28	45	45	US$ per barrel
Pass. cars	137	54	185	108	185	109	100 mn cars
Pass..car km	1696	561	2643	1524	2643	1533	bn km road
Ton km	881	109	1252	142	1252	163	bn km road
CO_2	0.9	1.3	1.1	1.8	0.8	1.0	Gton C
Carbon/GDP	0.3	1.1	0.2	1.0	0.2	0.4	kg C/ECU
NO_x	13.4	9.1	9.0	9.1	4.6	5.1	Mton NO_x
NO_x pass. cars	4.0	2.8	2.0	1.4	0.8	0.4	Mton NO_x
NO_x trucks	2.7	0.3	2.6	0.4	1.8	0.2	Mton NO_x
NO_x per pass.car km	2.4	5.0	0.7	0.9	0.3	0.3	g NOx km^{-1}
NO_x per tonkm	3.1	3.1	2.1	2.9	1.4	1.4	g NOx km^{-1}
SO_2	13.7	27.7	7.7	20.7	2.2	5.5	Mton SO_2
NH_3	4.2	5.0	4.3	5.4	2.4	3.1	Mton NH_3
VOC	13.0	12.6	8.0	9.6	5.0	3.6	Mton VOC
Agric.area	151	362	140	358	128	358	mn ha
Livestock	1240	1770	1584	2221	1430	2221	mn
Animals per ha.	8	5	11	6	11	6	
N-manure	8	10	8	10	8	10	Mton N
Use N Fert.	12	14	13	18	10	17	Mton N
Total N	17	21	19	25	16	25	Mton N
N per ha.	113	58	136	70	125	70	kg ha^{-1}
Pesticides	100	100	100	100	40	48	index
Acidification costs	-	-	27	25	64	57	bn ECU
Costs acid./GNP	-	-	0.6	1.4	1.4	2.5	%
Total costs min.	-	-	109	98	258	229	bn ECU
Total costs max.	-	-	136	123	322	287	bn ECU
Costs/GDP min.	-	-	2	5	4	8	%
Costs/GDP max.	-	-	3	7	7	13	%
Benefits E saving	-	-	4	0	4	74	bn ECU

sponding temperature increases, calculated for GLOBE I, GLOBE II and four additional scenarios, are presented in figure C

An assessment of the regional temperature change pattern over Europe at CO_2 doubling (in summer and winter) are presented in figure D. Figure E presents areas and vegetation types in Europe which may become endangered under a doubling of CO_2, because there is no similar vegetation type available in the surrounding 50-80 km.

It can be concluded that GLOBE I is a high-risk scenario in terms of both absolute temperature change and rate of change. A certain climatic risk for the coming decades is also implied in the GLOBE II scenario, and even in the 'Toronto' scenario. Introduction of a worldwide 'eco-tax' in the GLOBE I scenario, rising from zero in the year 1990 to 10 US-dollars per barrel in the year 2000, would reduce CO_2-equivalent concentrations and consequent temperature increase only by 5%. If Europe were to choose a different scenario from the rest of the world, the difference in expected temperature rise would be about 10%. Europe's historical contribution to global warming is approximately 30%.

Acidification:

Exceedances of critical loads for the most sensitive ecosystems in 1990 are presented in figure G. Figures H (GLOBE I) and I (GLOBE II) present exceedances of critical loads for 2010.

In 1990 more sensitive ecosystems in 73% of the European area were subjected to depositions exceeding the critical loads for acidity. In 1990 the areas with the largest excess (> 2000 eq ha^{-1} per year) cover 10% of Europe.

According to the GLOBE I scenario, in 2010 the area which is subjected to depositions exceeding the critical loads for acidity for the most sensitive ecosystems is reduced to 57% of the European area. The areas with the largest excess decrease to 3% of Europe.

According to the GLOBE II scenario the area which is subjected to depositions exceeding the critical loads for acidity for the most sensitive ecosystems is reduced to 30% of the European area. The areas with the largest excess are no longer found in 2010.

It can be concluded that the acidification of European soils will continue, due to deposition of sulphur and nitrogen compounds (including ammonia). Current (1991) depositions exceed the 'critical acid loads' for ecosystems in 63% of the total European area. In GlOBE II there will be considerable improvements.

General conclusions:

Two general conclusions regarding the potential impacts on human health and ecosystems can be derived. With regard to human health, the conclusion appears to be justified that the health of many inhabitants in Europe is influenced negatively by exposition to concentrations of environmental pollutants. Considerable differences between Eastern and Western Europe exist, but a quantitative evaluation of the relative impact on human health by factors such as food safety, nutrition, primary health and lifestyle has yet to be made.

With regard to ecosystems it can be concluded that, in general, critical levels are exceeded in all nature areas in Europe, under the assumption that appropriate critical levels have been used. Climatic change will become a dominant threat in all parts of Europe compared to the threats offered by acidification and eutrophication. Ecosystems in the boreal region will be particularly threatened by climate change.

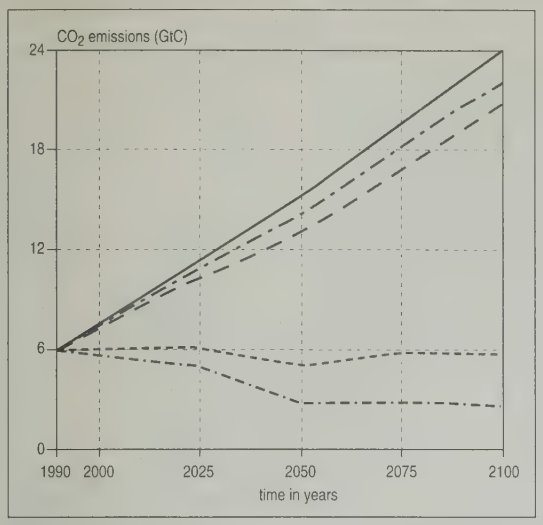


Figure A:
Global CO_2 emissions due to fossil fuel combustion; for GLOBE I, II and three scenario variants

Globe I scenario
EC Ecotax scenario
Europe Globe II scenario + Rest of World Escape Globe I scenario
Europe Escape Globe I scenario + Rest of World Globe II scenario
Globe II scenario

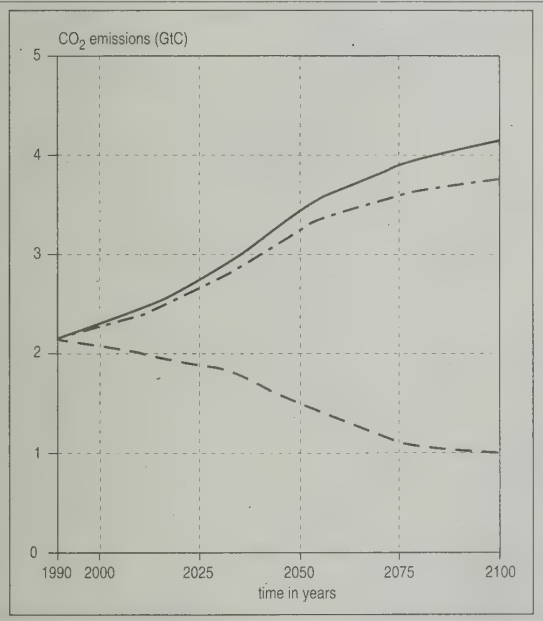


Figure B:
European CO_2 emissions due to fossil fuel combustion; for GLOBE I, II scenarios

Europe Globe I scenario
Europe Ecotax scenario
Europe Globe II scenario

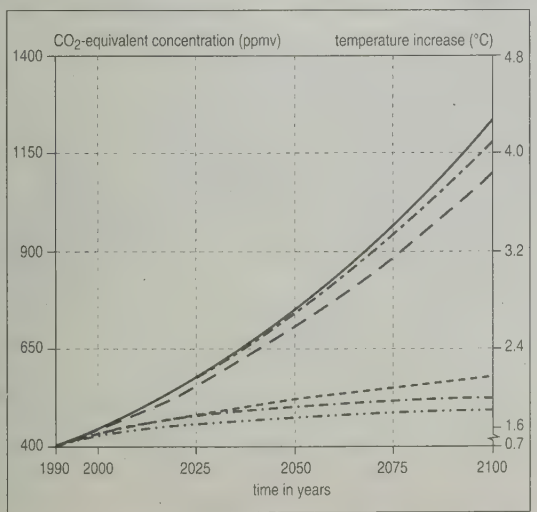
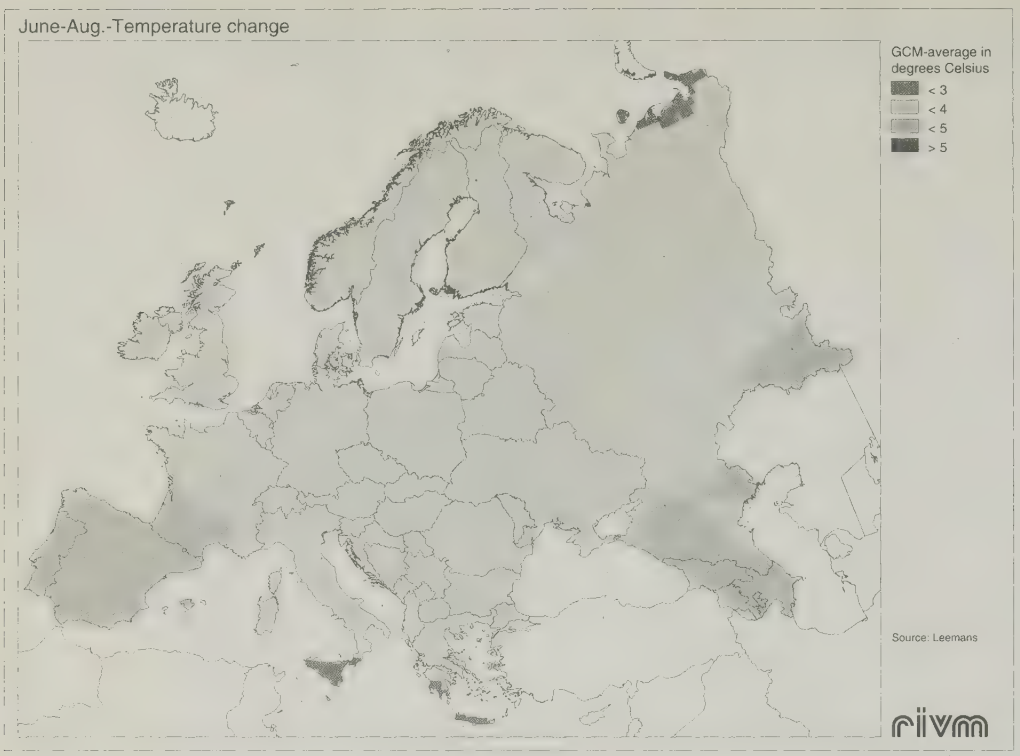


Figure C:
CO_2 equivalent concentrations and corresponding temperature increases for GLOBE I and II senarios and variants

Globe I scenario
EC Ecotax scenario
Europe Globe II scenario + Rest of World Escape Globe I scenario
Europe Escape Globe I scenario + Rest of World Globe II scenario
Globe II scenario
Toronto scenario



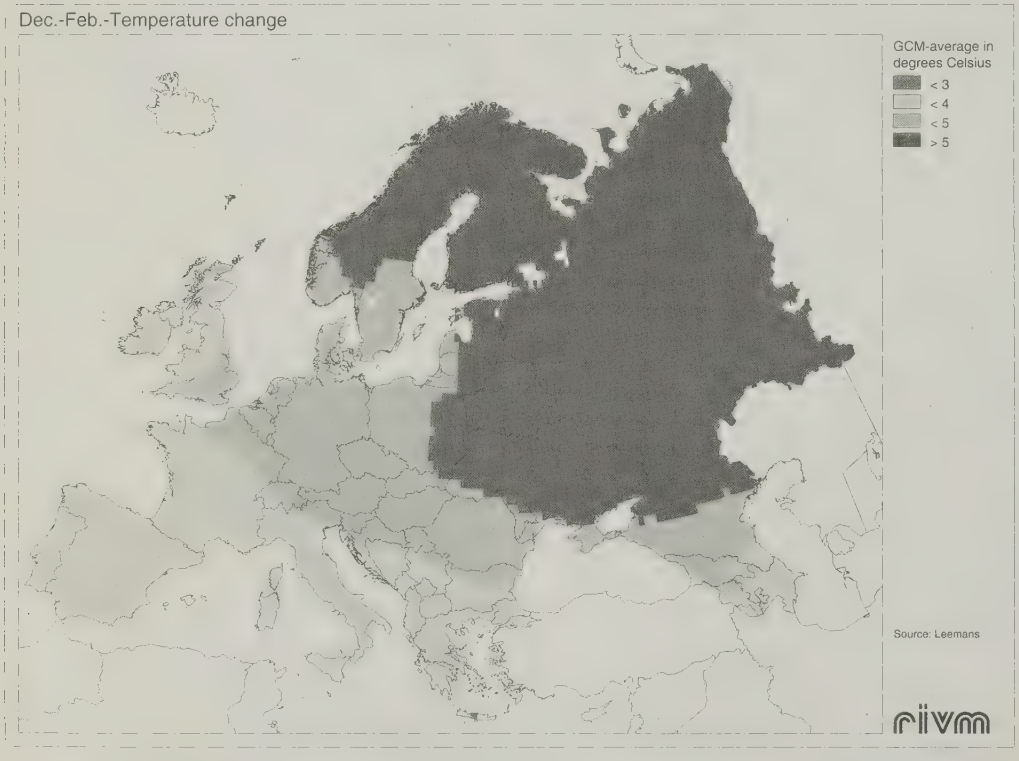


Figure D: Regional temperature change pattern in Europe at CO_2 doubling
Upper map: June-Aug temperature change
Lower map: Dec-Feb temperature change

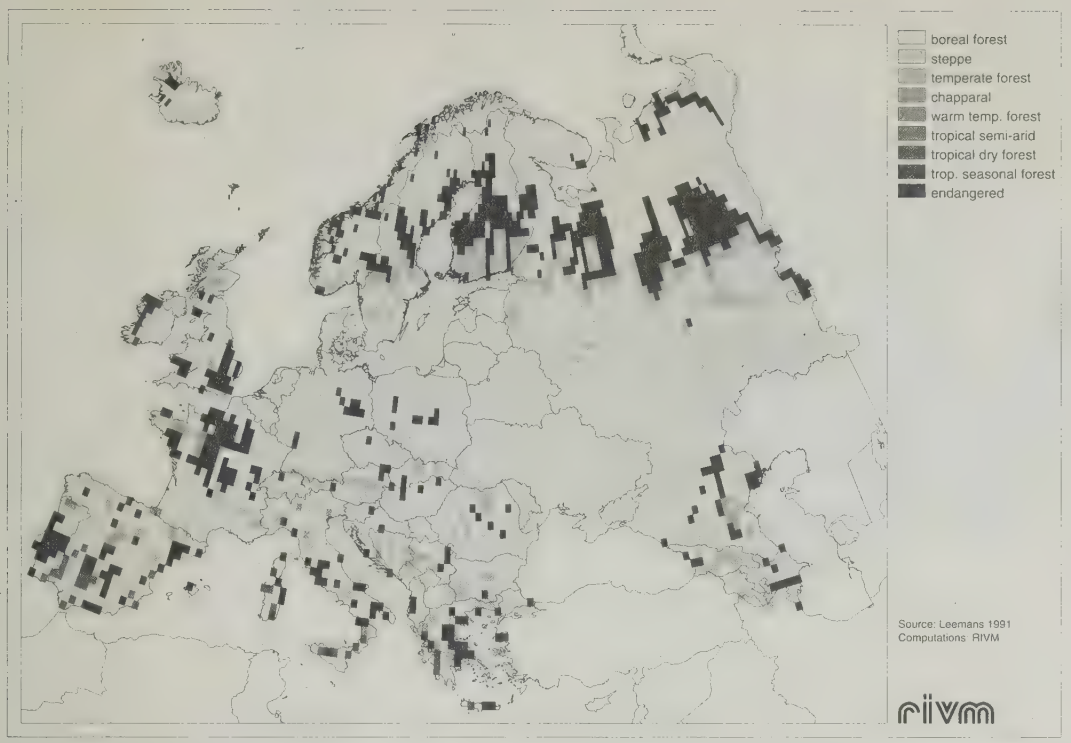


Figure E: Areas in Europe wich will become endangered under a doubling of CO_2, because there is no similar vegetation type available in the surrounding 5080 km

Figure F: Total loads of acidifying compounds in Europe in 1990

Figure G: Exceedances of critical loads in 1990

SOCIETAL RESPONSES

Table B presents European cost estimates related to the reduction of acidifying compounds for GLOBE I and GLOBE II.

The total costs for acidifying compounds (in GLOBE II) amount to 1.5% of GDP in Western Europe and 2.5% of GDP in Eastern Europe. The cost-effectiveness of the additional abatement measures in GLOBE II is higher in Eastern European countries.
Rough estimates of the total costs of GLOBE II were made on the basis of a comparison with the cost estimates for the Netherlands, where acidification abatement costs for a GLOBE II scenario are about 20-25% of the total costs. Ceteris paribus this results in a total annual estimated rise for GLOBE II up to 200-300 ECU for both Western and Eastern Europe in 2010: 5-7% of GDP in Western Europe and 10-13% of GDP in Eastern Europe.

Table B: Abatement costs acidifying compounds (annual costs 2010 in bn ECU)

	GLOBEI			GLOBE II		
	WE	EE	TOTAL	WE	EE	TOTAL
NO_x	17	14	31	29	24	54
SO_2	10	7.6	18	21	19	40
NH_3	0.2	2.5	2.7	14	14	28
TOTAL	27	24	52	64	57	122

Figure H: Exceedances of critical loads of acidifying compounds in Europe, GLOBE I scenario, 2010

Figure I: Exceedances of critical loads of acidifying compounds in Europe, GLOBE II scenario, 2010

SUMMARY

In summary, in the "The Environment in Europe: a Global Perspective" a first attempt is made to develop an integrated assessment of the past, current and future state of the environment of a continent in the context of global developments. Coordination across the PSIR environmental management cycle was achieved through the application of thematic integrated models, with the emphasis on the environmental system (state of the environment and impacts). Integration across different environmental issues was achieved through the application of the same consistent scenarios for all themes. As such, the study is an improvement over a combination of independent, partial assessments of the national environments. Nevertheless, the study does not yet comply with all the requirements of a fully integrated assessment. The policy-relevancy of the report would have been still greater, if it would have been developed in a broader international network of European experts and institutions. Technically, limited knowledge prevented a full appreciation of interactions between different environmental changes, such as multi-stress impacts. Also, the analysis of the relationship with socio-economic development in general was limited. Nevertheless, we believe that the study provides an excellent example of the feasibility of an integrated environmental assessment at the international level.